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AUTOMATIC SENSITIVITY ANALYSIS FOR AN ARMY MODERNIZATION OPTIMIZATION MODEL

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John Peter Johnson

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Thesis Advisor: Richard E. Rosenthal

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This is an extremely turbulent period for the post-cold-war Army. Even though the tempo of operations has increased dramatically worldwide, a peace dividend is demanded, consequently placing substantial constraints on the Army's capital budgeting process. In spite of this, the senior leadership is determined to maintain a first-rate force capable of meeting the challenges of the future.

Currently, the Office of the Deputy Chief of Staff for Operations and Plans (DCSOPS), United States Army, is reviewing a decision tool known as the Research, Development and Acquisition Alternative Analyzer (RDA^3) to support the development of the Army Modernization Plan (AMP). RDA^3 is a mixed integer optimization model formulated in the General Algebraic Modeling System (GAMS) by Donahue (1992). It prioritizes modernization actions and optimally allocates scarce research and development funds.

The goal of this thesis work is to enhance RDA^3 to provide the user with a more robust decision tool capable of providing a complete analysis of the entire decision space. Specifically, this study focuses on the unfunded investment projects in the RDA^3 solution, which are collectively called the *losers list*. The idea is to automatically provide explanatory information as to why each project on the losers list is unfunded. This study uses techniques developed by Chinneck (1993) for identifying infeasibilities in linear programming models. Chinneck's techniques are specialized for the RDA^3 context and extended to integer programming. Additionally, the idea of controlling the amount of change from one model run to another, known as persistence, is applied to RDA^3.

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AUTOMATIC SENSITIVITY ANALYSIS FOR AN ARMY MODERNIZATION OPTIMIZATION MODEL

John Peter Johnson
Captain, United States Army
B.S., United States Military Academy, 1985

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Author: John P. Johnson
John Peter Johnson

Approved by: Richard E. Rosenthal
Richard E. Rosenthal, Thesis Advisor

K. T. Marshall
Kneale T. Marshall, Second Reader

Peter Purdue, Chairman,
Department of Operations Research

ABSTRACT

This is an extremely turbulent period for the post-cold-war Army. Even though the tempo of operations has increased dramatically worldwide, a peace dividend is demanded, consequently placing substantial constraints on the Army's capital budgeting process. In spite of this, the senior leadership is determined to maintain a first-rate force capable of meeting the challenges of the future.

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

A. BACKGROUND

This is an extremely turbulent period for the post-cold-war Army. Even though the tempo of operations has increased dramatically worldwide, a peace dividend is demanded, consequently placing substantial constraints on the Army's capital budgeting process. In spite of this, the senior leadership is determined to maintain a first-rate force capable of meeting the challenges of the future.

Currently, the Office of the Deputy Chief of Staff for Operations and Plans (DCSOPS), United States Army, is reviewing a decision tool known as the *Research, Development and Acquisition Alternative Analyzer (RDA^3)* to support the development of the Army Modernization Plan (AMP). RDA^3 is a mixed integer optimization model formulated in the General Algebraic Modeling System (GAMS) by Donahue (1992). It prioritizes modernization actions and optimally allocates scarce research and development funds.

B. OBJECTIVE AND SCOPE

The goal of this thesis work is to enhance RDA^3 to provide the user with a more robust decision tool capable of providing a complete analysis of the entire decision space. Specifically, this study focuses on the unfunded investment projects in the RDA^3 solution, which are collectively called the *losers list.* The idea is to automatically provide explanatory information as to why each project on the losers list is unfunded. This study uses techniques developed by Chinneck (1993) for identifying infeasibilities in linear programming models. Chinneck's techniques are specialized for the RDA^3 context and extended to integer programming. Additionally, the idea of controlling the amount of change from one model run to another, known as persistence, is applied to RDA^3.

C. AUTOMATIC SENSITIVITY ANALYSIS FOR RDA^3

Understandably, the losers list is a pivotal issue and demands scrutiny. The general scheme is to attempt to force the losers one at a time into the optimal solution, re-solve the model and measure the effects. Both feasible and infeasible solutions are produced in these attempts. If forcing a loser into the solution causes infeasibility, Chinneck's algorithms are applied. Whereas Chinneck's research was motivated by the need to find data errors causing unintentional infeasibilities, the motivation for this study is to identify all the causes of infeasibility deliberately introduced.

D. APPLYING PERSISTENCE TO RDA^3

The degree to which a model maintains the previous solution from run to run is known as *persistence* (Brown, Dell, Farmer, 1995). As a capital budgeting model to be employed periodically by DCSOPS, RDA^3 requires a persistence capability for general acceptance. As the prioritizer of the U.S. Army, DCSOPS is not amenable to canceling projects and starting others everytime the budget changes. This study applies the persistence methodology to maintain consistency of results while performing sensitivity analysis on the budget profile. It is applied to study the impact of a budget change, while encouraging the original projects to remain in the solution.

E. CONCLUSIONS

RDA^3, by itself, is a useful decision tool. It rapidly assimilates data and provides an optimal mix of research projects and an optimal allocation of scarce research and development dollars. However, this may not be sufficient information to make a decision concerning billions of dollars. This study develops and implements a GAMS formulation, *Sensitivity Analysis for RDA^3*, that automatically investigates a great portion of the decision space. After running this program, the decision maker understands the tradeoffs involved with unfunded projects, and in some cases may determine that some losers could in fact be funded. Policy decisions, which include the mandatory funding of certain projects as well as the funding relationships, are thoroughly reviewed. For the baseline data in this study, most of the mandated projects gained credibility through this review, but there were a few that deserve further scrutiny. For those losers that are not funded due to conflicts in the funding relationships, a clear story is presented that articulates precisely what the conflicts are. In every case, the scope of the problem for each loser is dramatically reduced, thus allowing the decision maker to compare the merits of projects on a remarkably small scale.

Additionally, a manually directed sensitivity analysis of the budget is possible. Sensitivity Analysis for RDA^3, provides a capability to accomplish this in a way that is consistent with the decision maker's priorities. The decision maker can maximize the achievement of his capital budgeting goals, minimize the change to the current set of research projects, or seek a balance between achievement and change.

F. RELEVANCE TO THE ARMY

The usefulness of this study is directly linked to RDA^3's adoption as a capital budgeting tool for the United States Army. If DCSOPS decides to use RDA^3 in the development of the Army Modernization Plan, then the integration of Sensitivity Analysis for RDA^3 will substantially enhance the analysis. Otherwise, the Army should consider providing a similar automatic sensitivity analysis capability to whatever model is used. Further research and commitment to automating the analysis could potentially streamline the interactive process between decision makers and analysts, and accelerate the overall decision cycle.

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I. INTRODUCTION

A. HISTORY OF THE PROBLEM

In September 1992 the Naval Postgraduate School delivered a decision tool designed to provide the United States Army's Training and Doctrine Command (TRADOC) with a flexible and responsive means of prioritizing modernization actions and optimally allocating scarce research and development funds. (Donahue, 1993) Proposed modernization actions for the Army consist of a wide variety of investment projects, from weapon systems to communication equipment, all intended to meet forecasted requirements as determined by the senior leadership. The decision tool is called the Research, Development and Acquisition Alternative Analyzer (RDA^3). RDA^3 is a mixed integer optimization model formulated in the General Algebraic Modeling System (GAMS). It provides a decision maker or an analyst with an optimal mix of investments from the original shopping list of proposals. Subsequent sensitivity analysis must then be done by manually changing parameters within the model and re-solving the optimization.

Currently the RDA^3 model is being reviewed for use by the Office of the Deputy Chief of Staff for Operations and Plans (DCSOPS), U.S. Army. As a co-sponsor for this study, DCSOPS has identified the need for some improvements to the model. This study addresses those needs and provides additional recommendations for improvement.

B. OBJECTIVE

The goal of this thesis work is to enhance the existing model to provide the user with a more robust decision tool capable of providing a complete analysis of the entire decision space. Specifically, this study focuses on the unfunded investment projects from the initial

RDA^3 model results, which are collectively called the *losers list.* The idea is to automatically provide the maximum amount of explanatory information as to why each project on the losers list is unfunded. This automatic sensitivity analysis is done efficiently in terms of time to execute.

C. CURRENT ARMY BUDGET ENVIRONMENT

1. Situation

This is an extremely turbulent period for the post-cold-war Army. Even though the tempo of operations has increased dramatically worldwide, a peace dividend is demanded, consequently placing substantial constraints on the Army's capital budgeting process. In spite of this, the senior leadership is determined to maintain a first-rate force capable of meeting the challenges of the future. To accomplish this, an aggressive modernization program will be pursued as the drawdown continues. Figure 1 shows the declining defense budget allocation from 1989 to 1995. For FY 1995, the Army's overall budget, known as the Total Obligation Authority (TOA) was approximately $61.2 billion. Of this, 18.6% or $11.4 billion was allocated to research, development, and acquisition (RDA) funding. The forecasted amount for FY 1996 is a reduction to $10 billion and the downward trend is expected to continue. The Army's wish list of modernization actions greatly exceeds these amounts, hence the need for a decision tool that can prioritize and perform trade-off analysis. (Schmidt, May 1995)

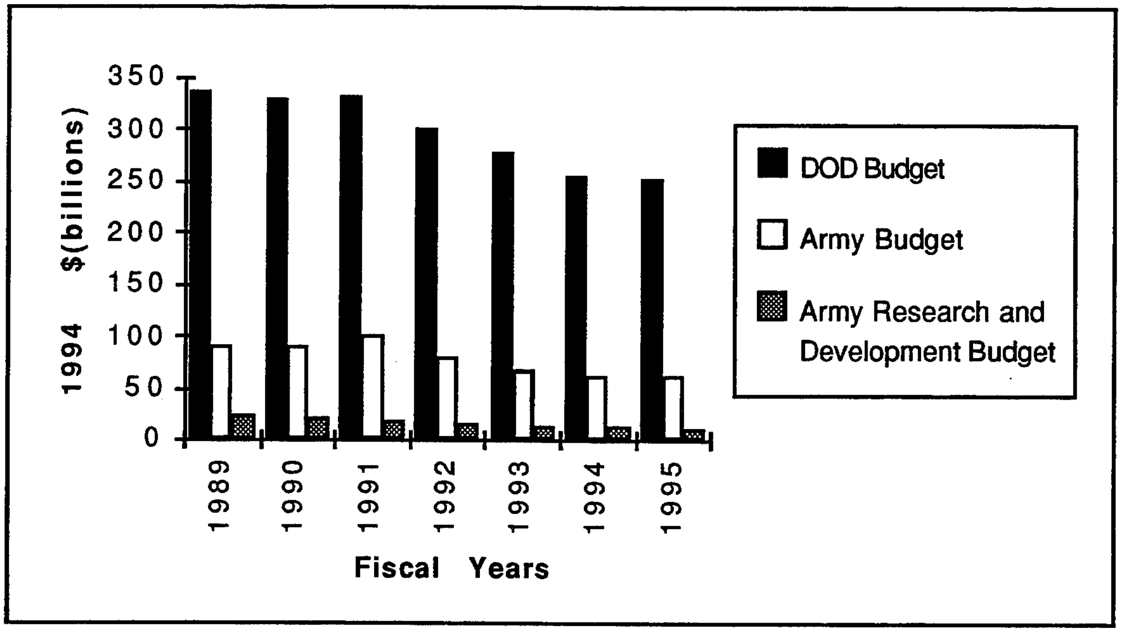

Figure 1. Budget Allocation FY89-FY95

2. Decision Making Demands

The reality of the Army's complex budgeting and procurement environment demands the presentation of options, as well as rationale for projects that go unfunded. Due to the decision maker's potential unfamiliarity with, or skepticism of mathematical programming models, the model must be able to anticipate sensible concerns. The decision makers want to know the impact of changes they may direct to the optimal mix of projects. Additionally, sponsors of unfunded proposals will expect justification. The objective for this study is to meet these demands and thus provide a useful decision tool.

II. DECISION SUPPORT MODELS FOR ARMY MODERNIZATION

This chapter provides the requisite background information on the Army's modernization program as well as the decision models used to prioritize projects and allocate funds. A detailed summary of RDA^3 (Donahue, 1992) is included to facilitate the reader's understanding of the enhancements implemented by this study.

A. ARMY MODERNIZATION PLAN (AMP)

The Army develops its modernization plan after a careful evaluation of the strategic environment and the U.S. National Military Strategy. The current assessment of the strategic environment is that it is uncertain and unstable. A 300% increase in the number of operational deployments since 1989 is clear evidence of this assessment. The interested reader is directed to the 1995 United States Army Modernization Plan (Army, 1995) for a detailed accounting of this summary.

1. Force XXI

The current vision of the 21st century Army is known as *Force XXI*. It is essentially a redesigned force capable of meeting the challenges of the future. The concept of Force XXI envisions intellectual and physical change from the status quo. Intellectually, the digitization of the force and use of advance simulations are the key ingredients. Physically, the Army's downsizing, return from Europe and conversion into a power projection Army represent significant modifications in the shape of the Army. The power projection Army, based in CONUS will be characterized by a broader range of missions, severely constrained resources, 21st century technology, and a shorter planning horizon for action (Army, 1994). The AMP is a critical element in transitioning today's Army to Force XXI. (Army, 1995)

a. Joint Operations Doctrine

Force XXI is derived from joint precepts and doctrine and therefore, supports the top five Future Joint Warfighting Capabilities, shown below and discussed in Volume Four (Future Capabilities) of the Joint Planning Document. The emphasis on joint and multi-national operations will continue to increase into the future.

- Near perfect real time knowledge of enemy and near real time dissemination
- Promptly engage regional forces in decisive combat on a global basis
- Employ capabilities suitable to actions at the lower end of the spectrum of military operations which allow achievement of military objectives with minimum casualties and collateral damage
- Control the use of space
- Counter weapons of mass destruction and future ballistic and cruise missiles to CONUS and deployed forces.

(Army, 1995)

b. Modernization Objectives

The Army modernization objectives which support the joint doctrine and are necessary to accomplish the National Military Strategy of *Flexible and Selective Engagement* are listed below (JCS, 1995):

- Project and sustain the force
- Protect the force
- Conduct precision strike
- Win the information war
- Dominate maneuver

The AMP provides information on the systems required to accomplish these objectives. Each objective is addressed by either enhancing current systems or introducing new technologies. The emphasis is capabilities, not systems. Therefore, the improvement and life extension of current systems is favored when possible (Army, 1994). The Army's systematic approach is intended to be evolutionary, although many revolutionary concepts will be synthesized into the process. (Army, 1995)

2. Decision Making Process

a. TRADOC's Role

TRADOC is the architect of the Army's future. As such, they are the author of the Long Range Army Material Requirements Plan (LRAMRP) which looks out to a fifteen year time horizon. (Donahue, 1992) TRADOC designed a process called the Concept Based Requirements System (CBRS) that determines the warfighting capabilities required by the Army (Schmidt, May 1995). Additionally, TRADOC develops the doctrine for how the Army trains and fights, and proposes recommendations to the leadership on how the force should be organized. The interested reader is directed to Donahue's work (Donahue, 1992) for a complete review of TRADOC's role in the modernization process.

b. Project Advocates

A project advocate is defined here as an individual or organization that has a vested interest in the successful adoption and funding of a certain project. Within the Army's acquisition process there exist several advocates for any given system. The original initiator of the project request is certainly an advocate and may be a TRADOC training center such as the Infantry School, or a specific Unified or Specified Commander in Chief (CINC) such as the CINC Atlantic Command. Once a project is initiated Program Executive Officers (PEOs) and Program Managers (PMs) are assigned responsibility for its development. They are also active advocates for projects under their purview.

c. DCSOPS' Role

DCSOPS is the prioritizer of the Army Staff and, as such, is the author of the AMP, as well as one of the primary authors of the Program Objective Memorandum (POM). The POM is the Army's recommendation of planned expenditures for the ensuing five year period to the Department of Defense. DCSOPS determines which projects to initiate as well as how to allocate funds to projects currently under development. To accomplish this, DCSOPS must synthesis information from project advocates and then properly prioritize projects to meet the present and future needs of the Army. The result is known as the Army Research , Development, and Acquisition Plan (RDA Plan). (Schmidt, May 1995) It provides a 15-year plan of funding streams for the technologies and materiel solutions selected to meet the modernization objectives. DCSOPS also provides input into the Extended Planning Period (EPP), which looks five more years beyond the POM. The allocation of funds becomes a major and ongoing process, dictated by the ever fluctuating budget. (Schmidt, Jan 1995)

3. Categorization of Projects

Investment projects, known as Management Decision Packages (MDEP), considered for procurement are assigned to Battlefield Operating Systems (BOS). The BOS is a construct which clearly partitions all aspects of Army activity on and off the battlefield into sixteen areas. The Army balances emphasis between the BOSs so that no area is neglected, and indicates priority to those BOSs which are critical to the Army's vision of force modernization.

a. Battlefield Operating Systems (BOS)

- Air Defense (AD)
- Ammunition (AMM)
- Aviation (AVN)
- Command and Control (C2)
- Combat Service Support (CSS)
- Fire Support (FS)
- Horizontal Technology Integration (HTI)

- Base Operations Support (IBOS)
- Intelligence and Electronic Warfare (IEW)
- Information System Management (ISM)
- Science and Technology Base (ISTB)
- Training (ITRG)
- Testing (ITST)
- Maneuver (MAN)
- Mobility (MOB)
- Nuclear, Chemical and Biological (NBC)

(Schmidt, 1995)

b. Management Decision Packages (MDEPs)

The MDEP is a resource management tool designed to give visibility to certain projects (Schmidt, May 1995). MDEPs may encompass broad areas such as small arms weapons, or ammunition. Therefore, each MDEP classification usually includes a set of sub-projects. Donahue (1992) referred to these sub-projects as increments. *Projects* and *sub-projects* are the lexicon primarily used in this study for clarity. The relationship between MDEPs and increments is captured within the RDA^3 model, and will be discussed later.

B. DECISION SUPPORT MODELS

DCSOPS currently uses one decision model to guide the prioritization and allocation of funding. This model, known as Value Added Analysis (VAA) (Loerch,1992), effectively compares only high priority combat weapon systems. This type of system accounts for about 40 of the approximately 350 projects under consideration at any one time. Recognizing this shortfall, the Assistant DCSOPS for Force Modernization has tasked the Concepts Analysis Agency to integrate the RDA^3 model with VAA in order to completely evaluate all projects under consideration. (Schmidt, 1995)

1. Value Added Analysis (VAA)

VAA is a family of models developed by the Concepts Analysis Agency to optimize acquisition strategies across system types and to support decision making necessary to build the Army budget (Loerch, 1992). A key model within VAA is the

Explicit Effectiveness Module, where the effectiveness of each competing system is measured. This module uses results from combat simulations to assign effectiveness values to the systems. This methodology is not considered appropriate for comparing systems that cannot be explicitly modeled in a simulation, e.g., command and control systems, intelligence acquisition systems, etc. The interested reader is referred to Loerch (1992) for an in depth review of VAA.

2. Research, Development and Acquisition Alternative Analyzer (RDA^3)

As stated earlier, to facilitate the reader's understanding of the enhancements implemented in this study, more detail is now provided on RDA^3's development and structure. The following review is what is necessary to fully understand the scope of the present study, but is by no means exhaustive. The reader is directed to Donahue (1992) for a full discussion. RDA^3 is a mixed integer optimization model formulated in GAMS. Specifically, it is a multi-objective weighted linear goal program with the following goals and inelastic constraints:

Goals

- Maximize the total warfighting value for each year
- Maintain mission area balance
- Minimize funding turbulence

Inelastic constraints

- Fund mandated projects
- Adhere to budget restrictions
- Adhere to maximum operation and support costs
- Fund MDEPs incrementally
- Adhere to minimum incremental funding levels
- Enforce existing funding relationships (logical constraints)

The major strength of RDA^3 over VAA is its capability to compare all projects (MDEPs) under consideration regardless of their associated BOS category. This is due to the way the effectiveness measures for the projects are obtained. The *warfighting value* highlighted in the first goal is the measure of effectiveness assigned to each project. This effectiveness measure is currently obtained from an application of the Analytic Hierarchy Process (AHP), but could be easily replaced by another value assessment methodology. AHP solicits subjective views from subject matter experts through pairwise comparisons of all the projects under consideration and returns a ranking or prioritization scheme. Unfortunately, AHP is problematic because it has been shown to suffer from rank reversal (McQuail, 1993). This shortcoming is not the focus of this study.

The *mission areas* in the second goal of RDA^3 are used by TRADOC for project analysis, and are easily mapped into the BOS construct used by DCSOPS. The third goal is introduced to prevent significant spikes in the funding profile of any project throughout the time horizon. This goal encourages the allocation of funds to a project in a given year to be at least a pre-determined fraction of the previous year's funding, given that it was funded the year prior. The mandated projects in the first inelastic constraint are those projects that must be either partially or fully funded. The remaining inelastic constraints are described in the next section.

a. General Goal Program Formulation

The generic formulation for a goal program is shown below in Equation 2.1. Each goal constraint has an associated elastic variable or variables that account(s) for the stretching of the goal. The objective function minimizes these elastic variables, hence minimizing the total deviations from the aspired goals. This is done while maintaining strict compliance of the inelastic constraints and variable bounds. The identification of infeasibilities within a goal program is discussed in Chapter IV.

$$\begin{aligned} &\text{Minimize} \sum \textit{Deviation from the goals} \\ &\text{subject to: } \textit{goal constraints} \\ &\qquad\qquad\quad \textit{inelastic constraints} \\ &\qquad\qquad\quad \textit{variable bounds} \end{aligned}$$

Equation 2.1

b. RDA^3 Formulation

The RDA^3 formulation, extracted from Donahue (1992), is presented below. An annual minimum funding level constraint not present in the original formulation is also included. The indices, data, and variables are summarized in Tables 1-6. The goal weights and scaling factors are shown in Table 4. Familiarity with these parameters will assist the reader's understanding of the enhancements discussed later.

Set	Definition
i	Management decision packages (MDEPs) or projects
j	MDEP increments or sub-projects
k	Mission area that is the proponent for the sub-project
t	Fiscal years in the time horizon under consideration

Table 1. RDA^3 Indices (from Donahue(1992))

Input Parameter	**Definition**
$BUDGET_t$	Warfighting budget allocation ($1000) for fiscal year t
$ASPIRE_{ijt}$	Aspired level of funding ($1000) for the jth increment of MDEP i in fiscal year t
$TOTASPIRE_{ij}$	Total aspired funding ($1000) for the jth increment of MDEP i across the time horizon
$MINLEVEL_j$	minimum increment funding level for MDEP increment j across the time horizon if it is funded at all
$MINLEVYR_{ij}$	minimum annual funding level for the jth increment of MDEP i (not included in Donahue (1992) formulation)
$OSCOST_{ij}$	Operation and support costs ($1000) for the jth increment of MDEP i
$RAMP_{ij}$	Ramp-up funding factor for the jth increment of MDEP i; specified as a fraction of the previous year's funding level aspired for current year
$MANDATE_{ij}$	Congressionally mandated increment j of MDEP i; equals 1 if the jth increment of MDEP i is mandated; equals 0 otherwise
$SHAREDATA_{k,minimum}$	Minimum level of funding (% of annual budget) for mission area k
$SHAREDATA_{k,desired}$	Desired level of funding (% of annual budget) for mission area k
$SHAREDATA_{k,maximum}$	Maximum level of funding (% of annual budget) for mission area k
MAXOSCOST	Maximum value for operation and support costs ($1000) over the time horizon
$WARVAL_{ij}$	Composite priority weight factor (AHP warfighting value) for the jth increment of MDEP i

Table 2. Input Data (from Donahue (1992))

Derived scalar/parameter	Definition	Derivation
TOTOSCOST	Total operation and support costs ($1000) for all MDEP increments across the time horizon	$\sum_{IJ} OSCOST_{IJ}$
$MAXWARVAL_t$	Maximum warfighting value in fiscal year t; equals the sum of the proportional composite priority weight factors in fiscal year t	$\sum_i \sum_j \frac{WARVAL_{ij}}{TOTASPIRE_{ij}} \cdot \sum_{t' \leq t} ASPIRE_{ijt'}$

Table 3. Derived Data (from Donahue (1992))

Weights/Scaling Factors	Definition
WT1	Priority weight of warfighting goal
WT2	Priority weight of mission area balance goal
WT3	Priority weight of turbulence goal
$WEIGHT1_t$	Discounted weight of warfighting goal in fiscal year t
$WEIGHT2_t$	Discounted weight of mission area balance goal in fiscal year t
$WEIGHT3_t$	Elastic penalties for mission area balance goal in fiscal year t
$WEIGHT4_t$	Discounted weight of turbulence goal in fiscal year t

Table 4. Goal Weights and Scaling Factors (from Donahue (1992))

Decision Variable	Definition	Range
X_{ijt}	Fraction of aspired level of funding for the jth increment of MDEP i in fiscal year t	0 to 1
Z_{ij}	$\begin{cases} 1; & \text{if the jth increment of MDEP i is funded} \\ 0; & \text{otherwise} \end{cases}$	0 or 1

Table 5. Decision Variables (from Donahue (1992))

Positive Variable	Definition	Range
$NWARVAL_t$	Negative deviation from aspired warfighting value in fiscal year t	0 to $+\infty$
$NBAL1_{kt}$	Negative deviation from desired level of funding for mission area k in fiscal year t	0 to $+\infty$
$NBAL2_{kt}$	Negative deviation from minimum level of funding for mission area k in fiscal year t	0 to $+\infty$
$PBAL1_{kt}$	Positive deviation from desired level of funding for mission area k in fiscal year t	0 to $+\infty$
$PBAL2_{kt}$	Positive deviation from maximum level of funding for mission area k in fiscal year t	0 to $+\infty$
$NTURB_{ijt}$	Negative deviation from stable funding of the jth increment of MDEP i in fiscal year t	0 to $+\infty$

Table 6. Deviation Variables (from Donahue (1992))

Objective function:

$$\begin{aligned} Deviation = & \sum_t WEIGHT1_t \cdot NWARVAL_t + \sum_k \sum_t WEIGHT2_t \cdot NBAL1_{kt} \\ & + \sum_k \sum_t WEIGHT3_t \cdot NBAL2_{kt} + \sum_k \sum_t WEIGHT2_t \cdot PBAL1_{kt} \\ & + \sum_k \sum_t WEIGHT3_t \cdot PBAL2_{kt} + \sum_i \sum_j \sum_t \frac{WEIGHT4_t}{SCALTURB} \cdot NTURB_{ijt} \end{aligned}$$

subject to:

$$\sum_i \sum_j \frac{WARVAL_{ij}}{TOTASPIRE_{ij}} \cdot \sum_{t' \le t} ASPIRE_{ijt'} \cdot X_{ijt'} + NWARVAL_t = MAXWARVAL_t; \ \forall t$$

Achieve Desired Warfighting Value

$$\sum_{i \in k} \sum_{j \in k} X_{ijt} \cdot \frac{ASPIRE_{ijt}}{BUDGET_t} + NBAL1_{kt} + NBAL2_{kt} - PBAL1_{kt} - PBAL2_{kt} = SHAREDATA_{k,desired}; \ \forall k,t$$

Maintain Mission Area Balance

$$NBAL1_{kt} \le SHAREDATA_{k,desired} - SHAREDATA_{k,minimum}; \ \forall k,t$$

Minimum Mission Area Funding Level

$$PBAL1_{kt} \le SHAREDATA_{k,maximum} - SHAREDATA_{k,desired}; \ \forall k,t$$

Maximum Mission Area Funding Level

$$X_{ijt} \geq RAMP_{ij} \cdot X_{ijt-1} - NTURB_{ijt};\ \forall i,j,t$$

Minimize Funding Turbulence

$$X_{ijt} \geq MANDATE_{ij};\ \forall i,j,t$$

Fund Mandated Projects

$$\sum_i \sum_j X_{ijt} \cdot \frac{ASPIRE_{ijt}}{BUDGET_t} \leq 1;\ \forall t$$

Adhere to Budget Restrictions

$$\sum_i \sum_j OSCOST_{ij} \cdot \left(\sum_t X_{ijt} \cdot \frac{ASPIRE_{ijt}}{TOTASPIRE_{ij}} \right) \leq MAXOSCOST$$

Adhere to Maximum Operation and Support Costs

$$Z_{i,\text{"01"}} \geq Z_{ij};\ \forall i,j$$

Fund MDEPs Incrementally

$$\sum_t X_{ijt} \cdot \frac{ASPIRE_{ijt}}{TOTASPIRE_{ij}} \geq MINLEVEL_j \cdot Z_{ij};\ \forall i,j$$

Adhere to Minimum Incremental Funding Levels

$$X_{ijt} \geq MINLEVYR_{ij} \cdot Z_{ij}$$

Adhere to Minimum Annual Funding Levels (Not in Donahue (1992))

$$X_{ijt} \leq Z_{ij};\ \forall i,j,t$$

Link Discrete and Continuous Decision Variables

The last set of constraints, not included here, are what Donahue(1992) called the ***logical constraints***. These constraints represent the funding relationships that exist between projects. They are described in detail in Chapter IV, where the term logical constraints is redefined to include all constraints that contain only binary variables. Once again, for a complete derivation and explanation of RDA^3's formulation the interested reader is directed to Donahue (1992).

III. IDENTIFYING INFEASIBILITIES IN LINEAR PROGRAMS

A. BACKGROUND

Significant advances in computers and software currently enable the routine formulation and solving of large, complex linear programs. However, as in all programming, mistakes are made while formulating large tasks or while updating previous work. In optimization models these mistakes can produce infeasibilities. Professor John Chinneck of Carleton University, Ottawa has established the methodological groundwork for analyzing this type of infeasibility in linear programming. Although others, including van Loon, proposed ways of dealing with infeasibilities, Chinneck was the first to develop a sound theoretical basis, coupled with actual implementation, that guaranteed the identification of a minimal set of inconsistent constraints. (Chinneck and Dravniek, 1991, Chinneck, 1993) This chapter is a brief summary of Chinneck's work.

B. IRREDUCIBLY INCONSISTENT SYSTEMS

Van Loon first coined the term *irreducible inconsistent system (IIS).* (Chinneck and Dravniek, 1991) An IIS is an infeasible set of constraints to include variable bounds which would become feasible if any one member of the set is removed. Chinneck later refined the lexicon to include an *irreducibly inconstent set of functional constraints (IISF)*, which is a subset of an IIS. (Chinneck and Dravniek, 1991) The difference is the exclusion of variable bounds in the IISF. Figure 2 shows a set of constraints with the set {A,B,C} representing an IISF. The set of constraints shown in Figure 3 is not an IISF, however the sets {A,B,C} and {A,B,D} are both IISFs. One set alone only defines and explains a portion of the cause for infeasibility in the problem. Sometimes correcting (making feasible) one IISF by removing one of its constraints will also correct other IISFs. This is the case when two or more IISFs contain common constraints. Removing either constraint A or B in Figure 3 corrects both of the IISFs present. The identification of a single IIS or IISF is considered critical to fix problems associated with mistakes in programming.

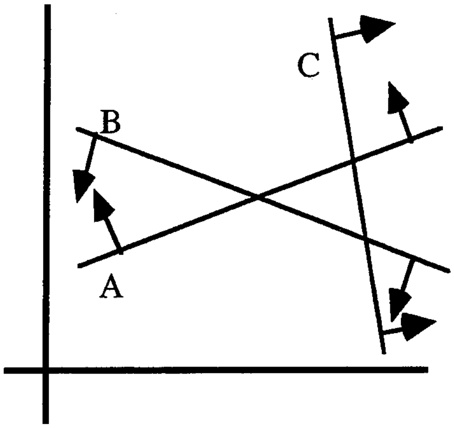

Figure 2. One IISF

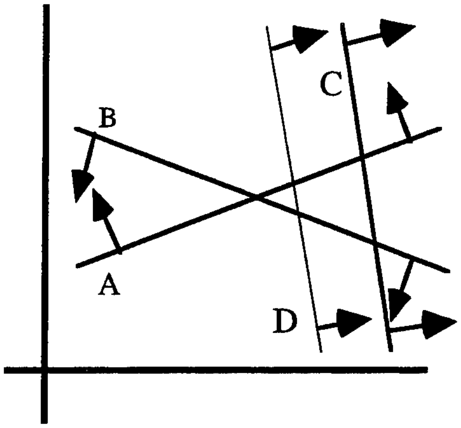

Figure 3. Two Overlapping IISFs

C. PINPOINTING INFEASIBLE CONSTRAINTS

In order to locate IISs and IISFs within an infeasible linear program Chinneck developed a series of algorithms called filters, as well as strategies to combine these filters for effective results. The four filters he developed are described below.

1. Deletion Filtering

Deletion filtering, by itself, is a brute force method of isolating a single IIS. The first step of the filter arbitrarily removes an existing constraint from the infeasible model. The model is then solved. If the model remains infeasible, the removed constraint is discarded (deleted). Otherwise, if the model becomes feasible, the removed constraint is replaced and another constraint is arbitrarily removed. This process is done iteratively until the removal of any constraint causes the model to become feasible. The remaining constraints together form an IIS. The IIS identified by the deletion process can change if the constraints are considered in a different order. Constraints deleted may in fact contribute to infeasibility and constraints that are members of the isolated IIS may also contribute to other IISs. The IIS that is isolated by this filter, is the one that coincidentally does not have a member constraint tested until at least one constraint in every other existing IIS has been tested. The constraints of every other IIS will be eliminated in the process because the system remains infeasible until the last IIS is identified. Although some of the other filters are quicker at eliminating constraints that do not contribute to the infeasibility, the deletion filter must be used to confirm the identification of a single IIS.

2. Sensitivity Filtering

To find an initial basic feasible solution, most linear programming solvers employ the two phase method. In Phase I, artificial variables are added to each constraint or some other mechanism is used to allow infeasibility, and the objective function becomes the minimization of the sum of infeasibilities. For the new problem to be feasible, the objective value must equal zero. If so, a basic feasible solution is identified and the optimal value is obtained during Phase II (Bazaraa, Jarvis, Sherali, 1990). This filter uses the Phase I results for the infeasible case to determine if a constraint should be removed from the system. When Phase I confirms infeasibility in the original model, the non-basic variables with positive reduced costs will be associated with bounds and constraints that contribute to the infeasibility. They are said to be sensitive to the Phase I efforts. All other constraints with associated non-basic variables having a reduced cost of zero are eliminated from the system. The sensitivity filter isolates all non-overlapping IISs, and in practice finds the largest row size IIS of overlapped IISs.

3. Reciprocal Filtering

The foundation for the reciprocal filter is the theorem which states that given either a variable or functional constraint has finite upper and lower bounds, if it is infeasible at one bound then it cannot be infeasible at the other bound within the same IIS. This filter can be used to eliminate unnecessary constraints by automatically identifying this condition while applying other filters.

4. Elastic Filtering

The elastic filter employs elastic programming techniques to identify IISs. The original model is converted to a pure elastic program by the addition of non-negative elastic variables to each functional constraint. These elastic variables allow each functional constraint to stretch beyond its bounds. The original objective function is replaced with the minimization of the sum of elastic variables. The form of the generic formulation conversion is displayed in Equation 3.1.

$$\begin{aligned}
&\textit{Min} \text{ or } \textit{Max} \text{ objective function } \Rightarrow \textit{Min}\sum_{ik} e_{jk} + \sum_{j} c_j x_j \\
&st.\ \sum_j a_j x_j \geq b_i \Rightarrow \sum_j a_j x_j + e_i \geq b_i \\
&\sum_j a_j x_j \leq b_i \Rightarrow \sum_j a_j x_j - e_i \leq b_i \\
&\sum_j a_j x_j = b_i \Rightarrow \sum_j a_j x_j - e_{i1} + e_{i2} = b_i
\end{aligned}$$

Equation 3.1 Conversion to an Elastic Formulation after (Chinneck, 1993)

When the system is solved the first time, at least one constraint in each IIS will stretch and an associated elastic variable will be positive. The stretched constraints are then forced to be feasible by removing their elastic variables from the formulation, and the system is re-solved. This process is repeated until the system is infeasible. Subsequent sets of stretched constraints may not include members from all IISs. The set of all enforced constraints contains at least one IIS with the last enforced constraint being a member of that particular IIS. Once again, the deletion filter is required to isolate a single IIS.

5. Strategies for the Integration of Filters

Chinneck devised several algorithms that combine the filters to make the search for infeasibility more efficient. The deletion filter can be used by itself to isolate an IIS. In practice, this option is time prohibitive for many large problems, hence the deletion filter is combined with the other filters to produce better results. One strategy is to use the deletion/sensitivity filter. This filter is the basic deletion filter with the sensitivity filter applied only if the system is infeasible on a deletion iteration. Another strategy is to apply the elastic filter and upon completion apply the deletion filter. The elastic filter's output is a set which contains at least one IIS and so the deletion filter then reduces the set to contain only one IIS.

Once an IIS is identified the programmer can focus on these constraints to determine the problem and implement appropriate corrections. This study implements an algorithm using the elastic filter in conjunction with the deletion filter to isolate all the non-overlapping IISs within an infeasible integer program.

IV. AUTOMATIC SENSITIVITY ANALYSIS FOR RDA^3

This chapter describes the methodology used to develop a thorough automatic sensitivity analysis of RDA^3. The central focus for the analysis is the losers list introduced in Chapter I. Understandably, this list of unfunded projects is a pivotal issue and demands scrutiny. The general scheme is to attempt to force the losers one at a time into the optimal solution, re-solve the model and measure the effects. Both feasible and infeasible solutions are produced in these attempts

If forcing a loser into the solution causes infeasibility, Chinneck's algorithms are applied. Whereas Chinneck's research was motivated by the need to find data errors causing unintentional infeasibilities, the motivation for this study is to identify all the causes of infeasibility deliberately introduced. As will be shown, the identification of causes of infeasibility presents a clear story to decision makers on the tradeoffs of projects and the impact of mandated funding.

In the cases when forcing a loser into the solution maintains feasibility, the automatic sensitivity analysis presents detailed information about the resulting tradeoffs.

A. POST-OPTIMALITY ANALYSIS

Like any deterministic model, RDA^3 may suffer from inexact model parameters. Hence, there exists room for error in the optimal solution based on its sensitivity to certain model parameters, such as the effectiveness coefficients assigned to each project. What can be asserted about RDA^3, is that the optimal solution is a "good" one. The most preferred solution by the decision maker, can only be ascertained from a systematic, and extensive post-optimality analysis. Post-optimality analysis in linear programming may include reoptimization, shadow price analysis, sensitivity analysis, and parametric linear programming. (Hillier and Lieberman, 1990)

1. Automatic Sensitivity Analysis

This study develops a robust sensitivity analysis methodology to the domain of the RDA^3 model. The idea is to automatically provide explanatory data on unfunded projects (losers list) as well as other areas. The methodology is implemented with a GAMS program (Appendix A). An option file (Appendix B), is used to control the scope of the automatic sensitivity analysis. This file is separate from the actual analysis code and well documented, hence equipping the unsophisticated user with an easy and flexible method of directing the analysis. Additionally, features are included in the option file to enable either the analyst or decision maker to effortlessly pursue other investigative avenues that are inefficient when implemented automatically. The capability to automate the sensitivity analysis was deemed essential to RDA^3's final acceptance as a decision tool. As described earlier, the Army's modernization decision making process demands a tool that not only obtains a good solution, but also one that quickly provides a thorough tradeoff analysis with other alternatives. This tradeoff analysis is as important as the optimal solution, since it provides the decision maker insights into the dynamics of the entire decision space.

2. Areas of Interest in RDA^3

This study primarily focuses on the losers list from the initial RDA^3 model results. Why did a project go unfunded and what is the impact of forcing an unfunded project into the optimal solution? Some unfunded projects would clearly violate explicit constraints in the model, causing an infeasible solution, whereas others would be feasible. These feasible projects, once forced into the optimal solution, will cause other projects to leave the solution and conversely may bring other losers into the solution. The display of these causal outcomes should prove insightful to the decision makers. The most turbulent model parameter is the annual budget level. In reality it can change daily, hence the capability of easily changing this model parameter will enable swift and responsive analysis. The budget analysis is addressed in Chapter V. Another aspect specific to the domain of RDA^3 is the mandating of projects. These policy decisions are certainly subject to review, therefore a complete mandated project analysis is included.

B. IDENTIFICATION OF INFEASIBILITIES

Since RDA^3 is a weighted goal program with many constraints allowed to "stretch", infeasibilities are confined to the set of inelastic constraints. An understanding of this is easily inferred from the general formulation of a goal program presented earlier in Chapter II, as well as the formulation of RDA^3. Additionally, Figure 4 graphically depicts a goal (elastic constraint), A, and inelastic constraints, B and C, of a simple goal program. If the desired feasible region is assumed to be as depicted, the goal (A) will adjust with appropriate increases in the deviation variables associated with it, thus becoming feasible. Conversely, the inelastic constraint, C is inflexible and will prevent the model from achieving feasibility. Clearly, infeasibilities can only be caused by the inelastic constraints.

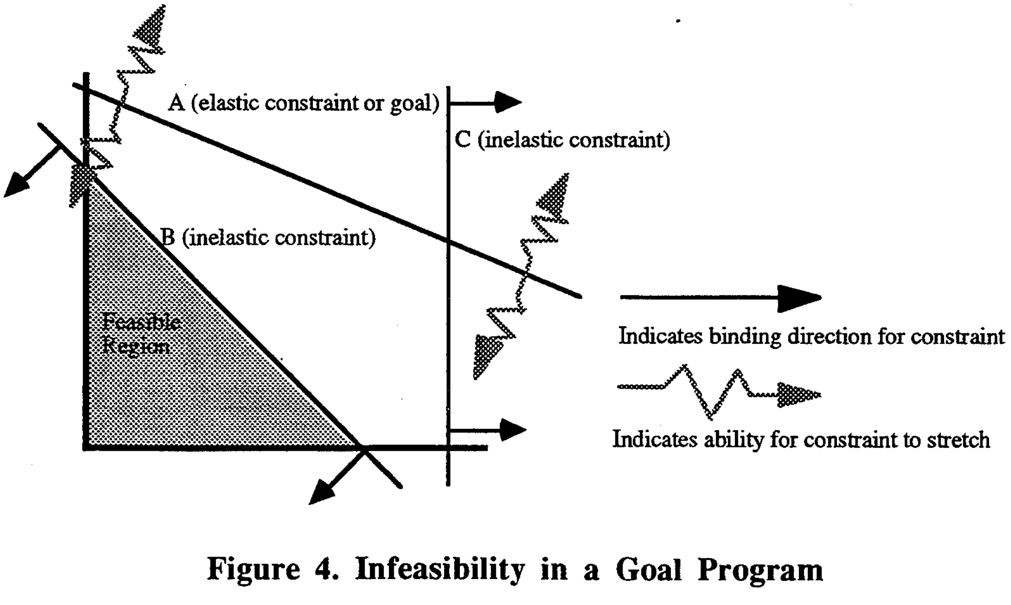

Figure 4. Infeasibility in a Goal Program

If forcing in a loser results in an infeasible solution, the decision maker may want to know which inelastic constraints are contributing to the infeasibility. Three types of inelastic constraints within RDA^3 are now reviewed.

1. Budget Constraint

Equation 4.1 enforces the annual budget levels in RDA^3. Forcing a loser into the solution may violate this constraint only if the sum of all the funds required by the mandated projects and the minimum funding level required by the forced in loser, exceeds the budget. This basic condition is tested for both the total funding levels and the annual funding levels. This type of infeasibility is tested without re-solving the model, thus making it efficient.

$$\sum_i \sum_j X_{ijt} \frac{ASPIRE_{ijt}}{BUDGET_t} \leq 1 \; ; \; \forall t$$

Equation 4.1

The chance of the budget constraint being violated in this way is minimal. However, given the solution from the original model, the test is very quick. RDA^3 was enhanced to enable either 100% funding of mandated projects or to allow partial funding determined by the optimization. Additionally, the addition of a minimum annual funding level constraint to RDA^3 further categorized the situation. Thus, the test for budget infeasibility, checks for the modus operandi and applies the appropriate evaluation. The algorithm pseudo-code for this test is shown in Figure 5.

Input: The losers list, formulation and optimal solution to RDA[3]
Output: Partition of losers list into budget feasible set and budget infeasible set.

```
Loop{over losers,
    Add to budget feasible set
    If minimum total aspired fraction < minimum annual funding fraction then
        If 100% funding of mandates required then
            Sum the funding for the mandates + minimum total
            aspiration for the forced in loser
            If Sum > total budget then
            Print 'Violates total budget constraint'
            Remove loser from budget feasible set
            Add loser to budget infeasible set
        Else if partial funding of mandates allowed then
            Sum the minimum funding level for the mandates +
            the minimum total aspiration for the forced in loser
            If Sum > total budget then
                Print 'Violates total budget constraint'
                Remove loser from budget feasible set
                Add loser to budget infeasible set
            }
        }
    }
    Loop{over years,
        If 100% funding of mandates required then
            Sum the funding for the mandates + the minimum
            funding level for the forced in loser
            If Sum > annual budget in this year then
                Print 'Violates budget constraint in this year'
                Remove loser from budget feasible set
                Add loser to budget infeasible set
        Else if partial funding of mandates allowed then
            Sum the minimum funding level for the mandates +
            the minimum funding level for the forced in loser
            If Sum > annual budget in this year then
                Print 'Violates budget constraint in this year'
                Remove loser from budget feasible set
                Add loser to budget infeasible set
    }
}
```

Figure 5. Algorithm for the Budget Test

2. Operating and Sustainment Cost (OSCOST) Constraint

The maximum operating and sustainment costs (MAXOSCOST) allowed for the entire time horizon of the analysis is enforced by Equation 4.2. Much like the budget constraint, a procedure that tests the impact of a forced-in loser and the mandated projects is necessary. Once again, the violation of this constraint is not expected, but it is easy to check, given the original model solution, and done without re-solving the model. The pseudo-code for the algorithm is identical to that shown for the budget constraint above, except total OSCOST for each project is summed and compared to the MAXOSCOST.

$$\sum_i \sum_j OSCOST_{ij} \frac{\left(\sum_t X_{ijt} \cdot ASPIRE_{ijt} \right)}{TOTASPIRE_{ij}} \leq MAXOSCOST$$

Equation 4.2

3. Logical Constraints

The more interesting sources of infeasibility are the logical constraints within RDA^3. Donahue (1992) defined the logical constraints to represent the funding relationships that exist between projects. He mathematically represented these relationships using binary variables and relational operators. For instance, if project A is funded then project B must also be funded translates to Equation 4.4 in Table 7, where Z_{ij} is a binary variable equal to one if the project is funded. These relationships are dictated by either policy decisions or by physical dependencies, such as, project A is a gun and project B is the ammunition for the gun. This study expands the definition of logical constraints to include any constraint in RDA^3 that contains only binary decision variables. This includes the incremental funding constraints (Equation 4.5) and the constraints that fix the binary variable for mandated projects to one (Equation 4.6). Table 7 displays the logical equations as defined by Donahue (1992) and expanded here. They are not all inclusive.

Equation Number	Logical Equation	Meaning
4.3	$Z_{ij} = Z_{i'j'}$	fund both sub-project j of project i and sub-project j' of project i' or neither
4.4	$Z_{i,\text{"01"}} \geq Z_{ij}\ ;\ \forall i,j$	fund the first sub-project of project i before other sub-projects
4.5	$Z_{ij} = 1$	must fund project i and sub-project j
4.6	$Z_{ij} + Z_{i'j'} \leq 1$	fund sub-project j of project i or sub-project j' of project i' or neither but not both
4.7	$Z_{ij} + Z_{i'j'} + Z_{i''j''} \leq 1$	fund at most one sub-project of either project i, i', i" or none at all
4.8	$Z_{ij} = Z_{i'j'} = Z_{i''j''}$ $Z_{ij} + Z_{i'''j'''} \leq 1$	fund either subset {ij,i'j',i"j"} or subset {i'"j'"}, but not both
4.9	$2Z_{ij} - Z_{i'j'} - Z_{i''j''} \leq 0$	fund sub-project j of project i only if sub-projects j and j" of projects i' and i" are funded
4.10	$-2 \leq Z_{ij} - Z_{i'j'} - Z_{i''j''} \leq 0$	fund sub-project j of project i only if sub-projects j or j" of projects i' and i" is funded
4.11	$Z_{ij} \geq Z_{i''j''}$	if sub-project j of project i is not funded, then do not fund sub-project j' of project i'
4.12	$2Z_{i''j''} \geq Z_{ij} + Z_{i'j'}$	if sub-project j of project i or sub-project j' of project i' is funded then must fund sub-project j" of project i"
4.13	$Z_{i''j''} \geq Z_{ij} + Z_{i'j'} - 1$	if sub-projects j and j' of projects i and i' are funded then must fund sub-project j" of project i"

Table 7. RDA^3 Logical Constraints (from (Donahue, 1992))

C. DEVELOPMENT OF AN RDA^3 SUB-MODEL FOR INFEASIBILITY TESTING

This study took advantage of the structure of RDA^3 by extracting the logical constraints and formulating a sub-model to which Chinneck's infeasibility identification algorithms could be efficiently applied. The obvious advantage of this approach was the exclusion of the majority of constraints (mainly elastic) from time consuming consideration by Chinneck's filter strategies.

1. Generic Representation of the Logical Constraints

The first step in developing the sub-model was the formulation and coding of the logical constraints in a generic form using GAMS. The reader is directed to Appendix C for a comparison of how the funding relationship constraints were formulated in the original RDA[3] and how they are presently done. It was a recommended enhancement by Donahue (1992) and should clearly save time in terms of syntactical correctness. It also made possible the simple formulation of the sub-model. The 'incremental funding' constraints, mathematically shown in Equation 4.5 and the 'funding relationship' constraints are represented as GAMS equations. The 'fixing of mandated projects' constraints (Equation 4.6) are enforced by explicitly including them in the formulation.

2. Sub-model Formulation

The sub-model was formulated as an elasticized pure integer program and is shown below. In this form, Chinneck's elastic filter is easily applied. Fixing all of the elastic variables to zero converts it to the proper form for the deletion filter.

Indices:

- lle = {EXC1, EXC2,...,} The set of $\leq$ funding relationship constraints
- leq = {COMP1, COMP2,...,} The set of = funding relationship constraints
- i = The set of projects (MDEPS)
- j = The set of sub-projects (MDEP increments)

Data:

- $ALE_{lle,i,j}$ = The coefficients of Z_{ij} for constraint lle
- $AEQ_{leq,i,j}$ = The coefficients of Z_{ij} for constraint leq

- BLE_{lle} = The right hand side value for constraint lle
- BEQ_{leq} = The right hand side value for constraint leq
- k = A small scaling constant less than one

Variables:

- $INFES_{lle}$ = Elastic variable accounting for stretching in less than or equal to constraints
- $PINFES_{leq}$ = Elastic variable accounting for positive stretching in equal to constraints
- $NINFES_{leq}$ = Elastic variable accounting for negative stretching in equal to constraints
- $INCINFES_{i,j}$ = Elastic variable accounting for stretching in the incremental funding constraints
- $MPINFES_{i,j}$ = Elastic variable accounting for positive stretching in the mandated project constraints
- $MNINFES_{i,j}$ = Elastic variable accounting for negative stretching in the mandated project constraints
- $Z_{ij} = \begin{Bmatrix} 1 \text{ if sub - project j of project i is funded} \\ 0 \text{ otherwise} \end{Bmatrix}$

Model:

$$\begin{aligned}
&Min \sum_{lle} INFES_{lle} + \sum_{leq}\left(PINFES_{leq} + NINFES_{leq}\right) + \sum_{ij} INCINFES_{ij} \\
&\quad + \sum_{ij}\left(MPINFES_{ij} + MNINFES_{ij}\right) + k \cdot \sum_{ij} Z_{ij}
\end{aligned}$$

$$\begin{aligned}
\text{st.}\quad & Z_{i,\text{"01"}} + INCINFES_{ij} \geq Z_{ij} \quad \forall i,j \\
& \sum_{ij}\left(ALE_{lle,i,j} \cdot Z_{ij}\right) - INFES_{lle} \leq BLE_{lle} \quad \forall lle \\
& \sum_{ij}\left(AEQ_{leq,i,j} \cdot Z_{ij}\right) - PINFES_{leq} + NINFES_{leq} = BEQ_{leq} \quad \forall leq \\
& Z_{ij} - MPINFES_{ij} + MNINFES_{ij} = 1 \ \forall \text{ mandated projects} \\
& Z_{ij} = \{0,1\} \\
& 0 \leq INFES_{lle} \leq 3 \ \forall lle \\
& 0 \leq PINFES_{leq} \leq 3 \ \forall leq \\
& 0 \leq NINFES_{leq} \leq 3 \ \forall leq \\
& 0 \leq INCINFES_{ij} \leq 3 \ \forall i,j \\
& 0 \leq MPINFES_{ij} \leq 3 \ \forall i,j
\end{aligned}$$

3. Strategy for Identifying the Infeasibilities.

The strategy for identifying logical infeasibilities is to iteratively force one loser into the solution, and apply Chinneck's elastic filter to locate as many infeasibilities as possible. As discussed earlier, the result is a set of infeasible constraints with at least one IIS. The deletion filter is then used to either verify that only the IIS was identified, which would mean that all infeasibilities were located, or to prove the existence of other IISs. Should other IISs exist, then additional applications of the elastic/deletion filter combination are required to isolate them. On subsequent applications, the constraints of any IIS clearly identified are kept elasticized during the elastic filter process. Each application of the elastic/deletion filter will either isolate another non-overlapping IIS or show that no more exist. A methodology for isolating overlapping IISs has not been implemented. Figure 6 is a flow chart of the strategy.

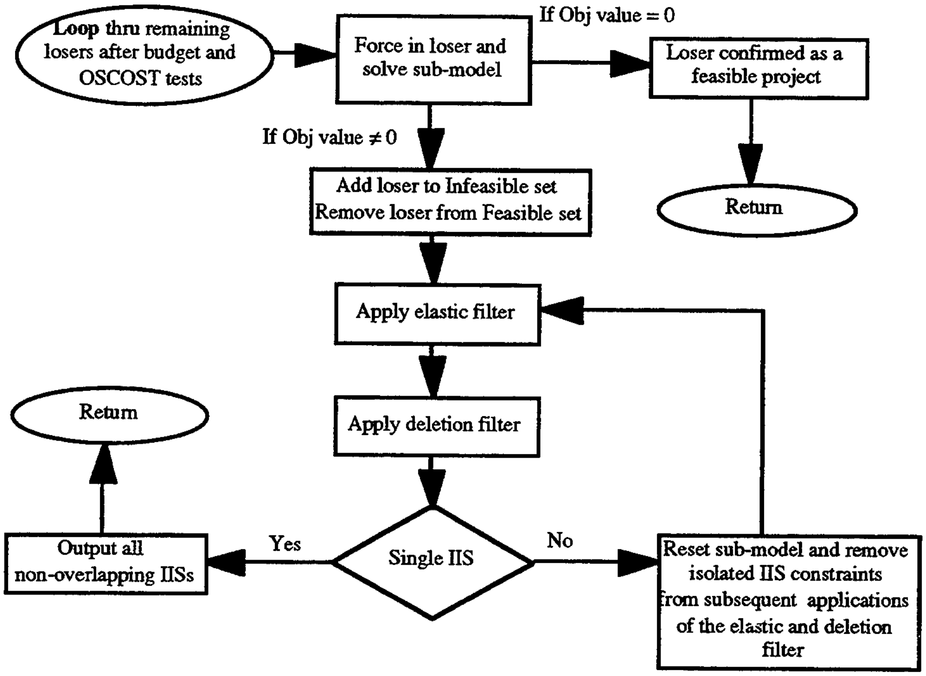

Figure 6. Flowchart for the Logical Infeasibility Identification

D. FEASIBLE PROJECT ANALYSIS

1. Single Project

The logical infeasibility identification process also specifies all of the feasible projects. Sensitivity analysis is performed by iteratively forcing them singly into the solution, re-solving the original RDA^3 model and observing what happens. The decision maker and analyst want to know the effects of modifying the initial model recommendations. This study implemented an analysis that automatically determines what projects are no longer funded (forced out), as well as what losers enter the solution (followed in) as a result of the force in. Additionally, the objective function value, and the deviation variable values are produced for comparative purposes. One should be able to compare the new objective function value with the previous one and determine the relative effect of forcing in a feasible loser. A comparison of deviation variable values should assist to pinpoint the real cause for the change. Most importantly, the decision maker will see the effects in real terms; e.g., if project A is forced in, he may find out that projects B,C,D,E,F and G are forced out (very expensive change), or he may find out that if project A is forced in that only project D is forced out. Now he may only have to compare the relative merits of the two projects to make a decision. Since the optimization for each force-in of a feasible project starts with the previous solution, the re-solving process is relatively efficient.

2. Multiple Projects

The ability to see the effect of simultaneously forcing in multiple projects into the solution is viewed as necessary and has been implemented in this study. However, it is not invoked automatically due to the combinatorially high number of options. The analyst can identify which projects to force in together in the option file. The analysis for the multiple projects is identical to the single project option.

E. MANDATED PROJECT ANALYSIS

1. Single Project

The mandated project analysis is performed very much like the feasible project analysis. Mandated projects represent policy decisions that rationally should be subject to review. The post-optimality analysis implemented here automatically studies the impact of un-mandating each of these projects, one at a time, and letting the model recommend whether they should be funded. The output is the same as for the feasible projects, highlighting those projects that enter the solution as well as those that leave. The new objective function value and goal deviations are also displayed. Congressionally mandated projects will be much more credible if it remains in the solution in this analysis.

2. Multiple Projects

Evaluating the effect of un-mandating multiple projects simultaneously is also accomplished like the feasible project analysis. Once again, the decision maker can easily direct scope of the study by manually identifying the desired mandated projects to be simultaneously un-mandated within the option file. The effects of this action are displayed as before.

V. APPLYING VARIABLE PERSISTENCE TO RDA^3

As stated, the most turbulent model parameters are the annual budget figures. Two distinct situations are investigated here: when the final project selection decision has not been made and when it has. Under the first condition, the decision maker may only require the conduct of general tradeoff analysis. At that point, the annual budget analysis is just another area of interest that is finalized prior to the final decision run. To accommodate this situation, the annual budget allowances can be modified for standard sensitivity analysis.

Once a decision on the funding of projects is made, changes to the funded projects list is undesirable. Annual budget fluctuations should then only affect the funding profiles of the selected projects. A methodology is introduced to deal with this situation.

A. APPLYING PERSISTENCE TO LINEAR PROGRAMS

1. Motivation

Models are often developed to support managerial decisions that are made periodically. Capital budgeting and scheduling models are two common examples. A given capital budgeting problem may forecast investments out twenty years, however, the funding strategy is commonly scrutinized and modified periodically to account for changes in the budgeting environment. Usually, it is undesirable for small changes in the environment to cause wholesale changes in the investment strategy. Unfortunately, this is a common trait associated with linear programming (LP) models, and is believed to deter some managers from accepting LP models as decision tool alternatives. The degree to which a model maintains the previous solution from run to run is known as *persistence.* (Brown, Dell, Farmer, 1995)

2. Encouraging Persistence

To compensate for the lack of persistence in most linear programs, Professors Gerald G. Brown, Robert F. Dell, and Kevin Wood (1995) developed a methodology that enables the decision maker to control the level of persistence in a given model. Persistence is encouraged by either fixing variables, penalizing deviations from previous solutions, or by setting aspirations for constraints.

a. Variable Persistence

The most basic form of variable persistence is to simply fix variables at their previous solution values. Since this strategy may result in an infeasible solution, a more robust technique is desired. One way is to create an elastic constraint for each variable that accounts for deviation from the aspired previous solution value. The general formulation is shown below.

Data:

- α = level of persistence $0 \leq \alpha \leq 1$
- wt^+ = penalty for positive deviation from previous solution
- wt^- = penalty for negative deviation from previous solution
- X_0 = vector of the previous solution's variable values
- b' = new vector of right hand side values
- A' = new matrix of coefficients
- C' = new vector of coefficients

Variables:

- X = vector of variables
- X^+ = vector of positive deviations from X_0
- X^- = vector of negative deviations from X_0

Model:

$$\begin{aligned} \textit{Minimize} \quad & (1-\alpha)C'X + \alpha(wt^{+} \cdot X^{+} + wt^{-} \cdot X^{-}) \\ \text{s.t.} \quad & A'X = b' \\ & X = X_0 + X^{+} - X^{-} \\ & X \geq 0 \\ & X^{+} \geq 0 \\ & X^{-} \geq 0 \end{aligned}$$

Another method that provides a level of persistence is to place bounds on variables equal to some fraction of their previous value. This is shown below where λ is the fraction of the previous value that the current variable is allowed to under or over achieve.

Model:

$$\begin{aligned} \textit{Minimize} \quad & C'X \\ \text{s.t.} \quad & A'X = b' \\ & (1-\lambda)X_0 \leq X \leq (1+\lambda)X_0 \\ & X \geq 0 \end{aligned}$$

b. Constraint Persistence

Persistence in an LP can also be encouraged in a similar fashion with constraints. This is done by converting constraints into goals (as in goal programming) with the aspiration or right hand side equal to the previous constraint value. Additionally, the constraints are maintained in their standard form with appropriate modifications to the coefficients and right hand sides that account for the change in the problem.

Data:

α = level of persistence $0 \leq \alpha \leq 1$

wt^+ = penalty for positive deviation from previous solution

wt^- = penalty for negative deviation from previous solution

X_0 = vector of the previous solution's variable values

b' = new vector of right hand side values

A = old matrix of coefficients

A' = new matrix of coefficients

C' = new vector of coefficients

Variables:

X = vector of variables

AX^+ = vector of positive deviations from AX_0 (over satisfaction)

AX^- = vector of negative deviations from AX_0 (under satisfaction)

Model:

$$
\begin{aligned}
\textit{Minimize}\quad & (1-\alpha)C'X + \alpha(wt^+ \cdot AX^+ + wt^- \cdot AX^-) \\
\text{s.t.}\quad & A'X = b' \\
& A'X = AX_0 + AX^+ - AX^- \\
& X \geq 0 \\
& AX^+ \geq 0 \\
& AX^- \geq 0
\end{aligned}
$$

3. Relevance

As a capital budgeting model to be employed periodically by DCSOPS, RDA^3 requires a persistence capability for general acceptance. As the prioritizer of the U.S. Army, DCSOPS is not amenable to canceling projects and starting others everytime the budget changes. This study applies the variable persistence methodology to maintain consistency of results while performing sensitivity analysis on the budget profile. It is applied to study the impact of a budget change, while encouraging the original projects to remain in the solution.

B. SENSITIVITY ANALYSIS OF RDA^3 WITH PERSISTENCE

Two variable persistence techniques were implemented. The first one fixes the funded projects into the solution and the model is re-solved. This will force the funds to be re-apportioned amongst the funded projects. If the budget outlay is increased additional projects may be funded, however, originally funded projects remain in the solution regardless of the budget change. If the solution becomes infeasible it means that the minimum funding level constraint was violated and will be identified by the previously discussed budget infeasibility test. The decision maker can then either, reduce the minimum funding level amount, or he can apply a more robust variable persistence technique.

The second variable persistence technique is the elastic constraint formulation. The variables are encouraged to remain at their previous values by elasticizing their explicit constraints and penalizing any deviation. The model formulation consists of the original RDA^3 model with the following additions and modifications.

Data:

- Wt^+ = penalty for positive deviation in the Z_{ij} variables
- Wt^- = penalty for negative deviation in the Z_{ij} variables
- α = desired level of persistence
- $Z01_{ij}$ = previous solution values for the Z_{ij} variables

Variables:

- Z^+_{ij} = Accounts for the positive deviation from the Z_{ij} variables
- Z^-_{ij} = Accounts for the negative deviation from the Z_{ij} variables

Model:

$$\begin{aligned}
\textit{Minimize}\quad & (1-\alpha)\cdot\left[\textit{original RDA}^{3}\ \textit{objective function}\right] \\
& +\alpha\cdot\left[\sum_{ij}\left(Wt^{+}\cdot Z_{ij}^{+}+Wt^{-}\cdot Z_{ij}^{-}\right)\right] \\
\text{st.}\quad & Z_{ij}-Z_{ij}^{+}+Z_{ij}^{-}=Z01_{ij}\quad \forall i,j \\
& \textit{original RDA}^{3}\ \textit{constraints} \\
& 0\le Z_{ij}^{+}\le 1\quad \forall i,j \\
& 0\le Z_{ij}^{-}\le 1\quad \forall i,j
\end{aligned}$$

The results of experiments with this formulation are reported in Chapter VI, Section F.

VI. DEMONSTRATION OF THE ANALYSIS

This chapter provides an exemplary analysis implementing the methodology introduced in Chapters IV and V. The baseline data set (Appendix H), provided by TRADOC Analysis Center, Ft. Leavenworth, Kansas, is the same one used by Donahue (1992) for the initial implementation of RDA^3. It is chosen because this work is regarded as an extension of Donahue's thesis. The data set is an unclassified sample, that includes 257 projects, and covers a fifteen year programming cycle from fiscal years 1994 to 2008. The data set is modified in some places to demonstrate a particular capability introduced by this study. These modifications are indicated. Important inferences and technical aspects are highlighted for each analysis presented within this chapter. The complete output of the analyses, is in Appendices D, E, F, and G.

A. IMPLEMENTATION

As discussed earlier, this study is implemented in GAMS (Appendix A) and executable on a personal computer. Prior to initiating the automatic and directed sensitivity analysis, the RDA^3 model must be run, and the RDA^3 post-optimization reports must be generated. The reports program simply calculates and presents data that are useful to the decision maker, such as the percentage of budget spent and percentage of aspired funding allocated for each project. The program developed for this study, *Sensitivity Analysis for RDA^3*, assimilates the information, conducts specified sensitivity analysis, and outputs summary response information to a text file. The baseline results for the automatic analyses are presented in Appendix D.

B. BUDGET, AND OPERATING AND SUPPORT COST INFEASIBILITY

This test is performed whenever either the logical infeasibility analysis, feasible project analysis, or the budget sensitivity analysis with a fixed solution is invoked. Three possible results of the analysis are demonstrated, with the data modified to create meaningful examples. However, the expected utility for this test is low, since it is highly unlikely for the budget profile to fall to the levels required to cause infeasibilities.

1. Feasible Budget and Operating and Support Cost

All of the losers for the original (baseline) RDA^3 data are budget and OSCOST feasible when the mandated projects are fully funded. (Appendix D) This implies that conflicts within the logical constraints are solely responsible for infeasible losers.

2. Infeasible Budget

Four cases, depicted in Table 8, are investigated when the budget profile is infeasible, meaning it is the cause for some losers to go unfunded. For cases 1 and 2 the total budget allocation is arbitrarily lowered to $25 billion from $165 billion. For cases 3 and 4, FY94, FY96, FY98, FY02, and FY06 budget levels are reduced to create infeasibilities. These figures and the complete output are provided in Appendix E. The results in Table 8 show the significant affects of the full versus partial funding policy for the mandated projects. There is a sharp reduction in the number of projects that go unfunded, when the policy for mandated projects is relaxed to allow partial funding.

Case	Minimum Fraction of Total Aspired to be Funded	Minimum Annual Funding Level	Funding Policy for Mandates	# Projects Not Funded Because They Violate the Budget Constraint
1	.6 for "01" increments .8 for all others	0	Full	15
2	.6 for "01" increments .8 for all others	0	Partial	2
3	0	.75	Full	25
4	0	.75	Partial	3

Table 8. Budget infeasibility results for the baseline data with the total budget allocation reduced to $25 billion from $165 billion are shown in cases 1 and 2. Cases 3 and 4 investigate the effect of placing a minimum annual funding level for each project funded and reducing particular annual budget levels to cause infeasibility. It is unlikely that the budget allocation would fall to these levels. For both situations, the relaxation to partial funding for mandated projects causes a sharp reduction in the number of projects not funded due to violating a budget constraint.

3. Infeasible Operating and Support Costs

To demonstrate the purpose of this test, the maximum allowable operating and support cost was reduced to $50 billion from $999 billion. This level creates the desired infeasibilities for the two cases investigated in Table 9. Once again, the effect of the mandated projects funding policy is dramatic. The complete output is in Appendix E.

Case	Maximum Allowable Operating and Support Cost	Funding Policy for Mandates	# Projects Not Funded Because They Violate the Maximum Operating and Support Costs
1	$50 Billion	Full	13
2	$50 Billion	Partial	1

Table 9. OSCOST infeasibility results for the baseline data with the maximum allowable operating and support cost reduced to cause infeasibility. The effect of the funding policy for mandated projects is evident. There is a substantial reduction in the number of projects that are not funded because they violate the maximum allowable operating and support costs.

C. FINDING THE LOGICAL INFEASIBILITIES

This section presents the mathematical representations of all the funding relationships contained in the baseline RDA^3 data, as well as the results after applying Chinneck's filters. These logical constraints, shown below, form the sub-model developed to efficiently find infeasibilities within the RDA^3 data. As discussed earlier, some losers are not funded because of conflicting funding relationships (logical constraints). Although it can be done, it is no easy task to visually identify these conflicts in the sub-model. The automatic identification of many of the conflicts (infeasibilities) simplifies this process.

1. Mathematical Representation of the Funding Relationships

Mandated Projects:

$Z_{FPEG,01} = 1$

$Z_{FPEL,01} = 1$

$Z_{FPEL,05} = 1$

$Z_{FPFL,01} = 1$

$Z_{FPJC,01} = 1$

$Z_{FPMK,01} = 1$

$Z_{FPMM,01} = 1$

$Z_{FPNC,01} = 1$

$Z_{FPSA,01} = 1$

$Z_{FPSA,06} = 1$

$Z_{FPSB,01} = 1$

$Z_{FPWB,01} = 1$

Incremental Funding Constraints:

$Z_{FL6V,01} \geq Z_{FL6V,02}$

$Z_{FL6X,01} \geq Z_{FL6X,02}$

$Z_{FPDA,01} \geq Z_{FPDA,02}$

$Z_{FPDB,01} \geq Z_{FPDB,04/05/06}$

$Z_{FPDE,01} \geq Z_{FPDE,02}$

$Z_{FPDC,01} \geq Z_{FPDC,06}$

$Z_{FPDH,01} \geq Z_{FPDH,04}$

$Z_{FPDQ,01} \geq Z_{FPDQ,02}$

$Z_{FPEA,01} \geq Z_{FPEA,02}$

$Z_{FPED,01} \geq Z_{FPED,02/04}$

$Z_{FPEE,01} \geq Z_{FPEE,02}$

$Z_{FPEG,01} \geq Z_{FPEG,04}$

$Z_{FPEH,01} \geq Z_{FPEH,04}$

$Z_{FPEL,01} \geq Z_{FPEL,02/05}$

$Z_{FPEN,01} \geq Z_{FPEN,04}$

$Z_{FPEP,01} \geq Z_{FPEP,06}$

$Z_{FPFM,01} \geq Z_{FPFM,05}$

$Z_{FPGA,01} \geq Z_{FPGA,02}$

$Z_{FPHE,01} \geq Z_{FPHE,02/03}$

$Z_{FPJA,01} \geq Z_{FPJA,02/04}$

$Z_{FPJB,01} \geq Z_{FPJB,02/04/06}$

$Z_{FPJC,01} \geq Z_{FPJC,02/04/06}$

$Z_{FPLF,01} \geq Z_{FPLF,04/06}$

$Z_{FPLG,01} \geq Z_{FPLG,02}$

$Z_{FPLK,01} \geq Z_{FPLK,02/04}$

$Z_{FPMC,01} \geq Z_{FPMC,05}$

$Z_{FPMH,01} \geq Z_{FPMH,02/03}$

$Z_{FPMJ,01} \geq Z_{FPMJ,05}$

$Z_{FPMK,01} \geq Z_{FPMK,04/06}$

$Z_{FPMM,01} \geq Z_{FPMM,04}$

$Z_{FPNE,01} \geq Z_{FPNE,02/05}$

$Z_{FPSA,01} \geq Z_{FPSA,06}$

$Z_{FPSB,01} \geq Z_{FPSB,04}$

$Z_{FPSD,01} \geq Z_{FPSD,04/06}$

$Z_{FPSE,01} \geq Z_{FPSE,02}$

$Z_{FPWB,01} \geq Z_{FPWB,06}$

$Z_{FPWC,01} \geq Z_{FPWC,04/05/06}$

$Z_{FPWD,01} \geq Z_{FPWD,04}$

$Z_{FPXK,01} \geq Z_{FPXK,02}$

$Z_{FPXX,01} \geq Z_{FPXX,06}$

$Z_{RA08,01} \geq Z_{RA08,06}$

$Z_{RA09,01} \geq Z_{RA09,02}$

$Z_{RA11,01} \geq Z_{RA11,04/06}$

$Z_{RA31,01} \geq Z_{RA31,06}$

$Z_{RC01,01} \geq Z_{RC01,02}$

$Z_{RD07,01} \geq Z_{RD07,04}$

$Z_{RD12,01} \geq Z_{RD12,02}$

$Z_{RF02,01} \geq Z_{RF02,02}$

$Z_{RF03,01} \geq Z_{RF03,04/06}$

$Z_{RF09,01} \geq Z_{RF09,06}$

$Z_{RG06,01} \geq Z_{RG06,02/03}$

$Z_{RH12,01} \geq Z_{RH12,04}$

$Z_{RH13,01} \geq Z_{RH13,04}$

$Z_{RJL4,01} \geq Z_{RJL4,02}$

$Z_{RJS2,01} \geq Z_{RJS2,05}$

$Z_{TA18,01} \geq Z_{TA18,04}$

$Z_{TA35,01} \geq Z_{TA35,04}$

Other Funding Relationships:

$Z_{FPHB,01} + Z_{FPSG,01} \leq 1$

$Z_{FPSF,01} + Z_{RF08,01} \leq 1$

$Z_{FPSB,01} + Z_{FPSJ,01} + Z_{RA09,01} \leq 1$

$Z_{FPSD,01} + Z_{FPNB,01} + Z_{FPDC,01} \leq 1$

$Z_{FPXX,01} + Z_{FPLK,02} + Z_{FPSD,01} \leq 1$

$Z_{FPEA,01} + Z_{FPGA,01} \leq 1$

$Z_{FPSA,01} + Z_{FPSE,01} \leq 1$

$Z_{FPEA,01} = Z_{FPEL,02}$

$Z_{FPEA,01} = Z_{FPEL,05}$

$Z_{FPSA,01} = Z_{FPSA,06}$

$Z_{FPSG,01} = Z_{FPSH,01}$

$Z_{FPHB,01} = Z_{FL6X,01}$

$Z_{RA08,01} = Z_{FPSE,01}$

$Z_{RA08,01} = Z_{RF01,01}$

$Z_{RA08,01} = Z_{RF08,01}$

$Z_{FPLF,01} = Z_{FPFL,01}$

$Z_{FPLF,01} = Z_{FPHC,01}$

$Z_{FPLF,01} = Z_{FPLG,01}$

$Z_{FPLF,01} = Z_{FPLX,01}$

$Z_{FPLF,01} = Z_{FPLC,01}$

$Z_{FPLF,01} = Z_{FPJA,01}$

$Z_{FPEA,01} = Z_{FPED,01}$

$Z_{FPEA,01} = Z_{FPEE,01}$

$Z_{FPEA,01} = Z_{FPLE,01}$

$Z_{FPFP,01} = Z_{FPWB,01}$

$Z_{FPFP,01} = Z_{FPFL,01}$

$Z_{FPFP,01} = Z_{FPFK,01}$

$Z_{FPFP,01} = Z_{FPFB,01}$

$Z_{FPFP,01} = Z_{FPWC,01}$

These equations form the constaints of the sub-model described in Chapter IV. Chinneck's filters are applied to isolate funding relationship incompatibilities for infeasible losers.

2. Baseline Results Summary

For the baseline data, 11 of 25 original losers are infeasible as a result of conflicts within the sub-model of logical constraints (Appendix D). If a constraint is identified by the elastic filter, and then not assigned to an IIS by the deletion filter, then it must belong to an overlapped IIS. The existence of several overlapped IISs were identified by the elastic filter process. The results from applying the elastic and deletion filters after forcing in project RA08,06 is shown below.

Force in: Project RA08,06 : $Z_{RA08,06} = 1$

Elastic Filter Application: The application of the elastic filter identifies at least one conflicting constraint in each IIS. Therefore, the force-in, RA08,06 is incompatible with the following funding relationships.

- $Z_{RA08,01} \geq Z_{RA08,06}$
- $Z_{FPSE,01} = Z_{RA08,01}$
- $Z_{FPSA,01} + Z_{FPSE,01} \leq 1$
- $Z_{FPSA,01} = 1$
- $Z_{FPSA,06} = 1$

Deletion Filter Application: The deletion filter then determines which of the constraints belong to one IIS. Notice that the constraint, $Z_{FPSA,06} = 1$, is not a member of the isolated IIS. This means that it is a member of an overlapped IIS. If one of the following funding relationships other than, $Z_{FPSA,01} = 1$, were removed, then RA08,06 would be feasible, and therefore could be funded.

- $Z_{RA08,01} \geq Z_{RA08,06}$
- $Z_{FPSA,01} = 1$
- $Z_{FPSA,01} + Z_{FPSE,01} \leq 1$
- $Z_{FPSE,01} = Z_{RA08,01}$

The existence of an overlapped IIS is shown above by the identification of the mandated constraint, $Z_{FPSA,06} = 1$, by the elastic filter, that is not subsequently assigned to an IIS by the deletion filter. For the relatively small set of logical constraints included in the sub-model, the analyst can easily find the offending set of constraints. For RA08,06, as well as the other infeasible losers, the analyst can now clearly communicate to its advocates precisely why it was not funded. The isolated IIS is interpreted as follows: FPSA,01 is mandated ($Z_{FPSA,01} = 1$), therefore FPSE,01 cannot be funded ($Z_{FPSA,01} + Z_{FPSE,01} \leq 1$). This implies that RA08,01 cannot be funded ($Z_{FPSE,01} = Z_{RA08,01}$), which, due to the incremental funding constraint ($Z_{RA08,01} \geq Z_{RA08,06}$), implies that RA08,06 cannot be funded. The overlapped IIS is caused by the constraint, $Z_{FPSA,01} = Z_{FPSA,06}$. In other words, the constraints, $Z_{FPSA,01} = 1$ and $Z_{FPSA,06} = 1$, are interchangeable with the isolated IIS. To fund RA08,06, the decision maker must re-define the funding relationships (logical constraints) associated with it. Only one funding relationship within each IIS needs to be removed, thus simplifying the process. At the very least, he now understands the relationship that exists between the loser and other projects and also knows exactly why it was not funded.

3. Introduction of Non-overlapped IISs

The intent of this section is to demonstrate the capability of the filter strategy implemented by this study to isolate non-overlapped IISs. First, the reader should understand that when only analyzing the losers list, forcing in one loser at a time precludes the appearance of non-overlapped IISs. Otherwise the original RDA^3 data would have been infeasible. An infeasible solution for RDA^3 is possible, considering the development of the numerous funding relationships may occur in an uncoordinated and disjoint fashion, and over a long period of time. Therefore, the ability to find non-overlapped IISs is essential to quickly identifying incompatible funding relationships. The original RDA^3 data becomes infeasible with the inclusion of the logical constraints (funding relationships) shown below.

$$Z_{FPSD,06} = Z_{FPNC,01}$$
$$Z_{FPSD,06} + Z_{FPMK,01} \leq 1$$
$$Z_{FPNC,01} = 1$$
$$Z_{FPMK,01} = 1$$

These added constraints form an IIS. The analysis performed after project RA08,06 is forced into the solution of the sub-model is shown below. Both its associated IIS, as well as the non-overlapped IIS intentionally introduced, are isolated by the filtering process. Once again, the reader should recognize the existence of a non-overlapped IIS, which is not isolated. The constraint, $Z_{FPSA,06} = 1$, is not assigned to an IIS, therefore it must be a member of an overlapped IIS.

Force in: Project RA08,06: $Z_{RA08,06} = 1$

1st Elastic Filter Application: The first application of the elastic filter identifies at least one constraint in every IIS. RA08,06 is incompatible with the following funding relationships.

- $Z_{RA08,01} \geq Z_{RA08,06}$
- $Z_{FPSE,01} = Z_{RA08,01}$
- $Z_{FPSA,01} + Z_{FPSE,01} \leq 1$
- $Z_{FPSA,01} = 1$
- $Z_{FPSA,06} = 1$
- $Z_{FPNC,01} = Z_{FPSD,06}$
- $Z_{FPMK,01} = Z_{FPSD,06}$
- $Z_{FPMK,01} = 1$
- $Z_{FPNC,01} = 1$

1st Deletion Filter Application: This filter isolates the following set of constraints, that together form an IIS and are incompatible with RA08,06. The order in which constraints were tested by this filter, dictated the first IIS to be isolated. It turns out to be the one intentionally introduced. The decision maker can fix the infeasibility in the RDA^3 data by studying these constraints and removing one or more that do not make sense. The constraints of this IIS are removed from the sub-model prior to searching for other IISs.

- $Z_{FPMK,01} = 1$
- $Z_{FPNC,01} = 1$
- $Z_{FPMK,01} = Z_{FPSD,06}$
- $Z_{FPNC,01} = Z_{FPSD,06}$

2d Elastic Filter Application: At least one constraint in any remaining IIS is identified by this filter. Notice that all of the constraints were already identified by the first elastic filter application.

- $Z_{RA08,01} \geq Z_{RA08,06}$
- $Z_{FPSE,01} = Z_{RA08,01}$
- $Z_{FPSA,01} + Z_{FPSE,01} \leq 1$
- $Z_{FPSA,01} = 1$
- $Z_{FPSA,06} = 1$

2d Deletion Filter Application: The remaining non-overlapped IIS is isolated. Once again, notice that the constraint, $Z_{FPSA,06} = 1$, is not assigned to an IIS and therefore belongs to an overlapped IIS. As demonstrated earlier, by locating logical constraints that contain FPSA,06, the analyst can determine the set of constraints that form this additional infeasible set of constraints. Forcing RA08,06, not only identified its associated IISs, but also identified the non-overlapped IIS that made the RDA^3 data infeasible.

- $Z_{RA08,01} \geq Z_{RA08,06}$
- $Z_{FPSE,01} = Z_{RA08,01}$
- $Z_{FPSA,01} + Z_{FPSE,01} \leq 1$
- $Z_{FPSA,01} = 1$

To locate the infeasibility in the original data, the loser forced in need not be an infeasible loser. If a feasible loser were forced in, the only isolated IIS would be the one that causes infeasibility in the original data.

D. MANDATED PROJECT ANALYSIS

Table 10 summarizes the analysis performed on the mandated projects that are members of an IIS. For the baseline model, there are four mandated projects that contribute to infeasibilities. From the specific results (Appendix D), one can see the effect of un-mandating these projects one at a time. Not only can one see the change in the budget allocation to the un-mandated project, but also the effect in real terms. How many projects are forced out of the solution and how many projects enter the solution as a result of the action. Credibility is strengthened for projects with no change to the solution or funding profile, such as FPSA,01 and FPSB,01. On the other hand, a mandated project may be questionable if it leaves the solution, such as FPEL,05.

This analysis can be repeated for all of the mandated projects as well. Results for this are located in Appendix F. Table 11 shows the results of simultaneously un-mandating the same 4 mandated projects that were members of an IIS. To see the effect of un-mandating all of the mandated projects, the analyst should re-solve RDA^3 with the partial-funding-for-mandates policy in effect.

Mandated Projects	# Projects Forced-out	# Projects Enter	% Funding Before	% Funding After	Objective Function
FPEL,05	16	5	100	0	889.88
FPSA,01	0	0	100	100	919.63
FPSA,06	0	0	100	80	916.65
FPSB,01	0	0	100	100	919.63

Table 10. Summary information after un-mandating those mandated projects that are incompatible with one or more losers. Credibility is gained when the funding level remains the same after un-mandating, as with FPSA,01. FPEL,05 deserves more scrutiny since it is no longer funded.

Mandated Projects	# Projects Forced-out	# Projects Enter	% Funding Before	% Funding After	Objective Function
Group Effect	19	10	n/a	n/a	799.03
FPEL,05	n/a	n/a	100	0	n/a
FPSA,01	n/a	n/a	100	0	n/a
FPSA,06	n/a	n/a	100	0	n/a
FPSB,01	n/a	n/a	100	100	n/a

Table 11. Summary information after un-mandating a group of mandated projects. The motivation for which ones to test is strictly up to the analyst. In this case, three leave the solution and one remains. Notice that the objective function value is greatly improved from the original value of 919.63.

E. FEASIBLE PROJECT ANALYSIS

There are 14 feasible losers in the baseline data. Forcing each feasible loser into the solution, one at a time, provides some very interesting results (Table 12). For example, FPJB,06, FPLF,06, FPLG,02, FPLK,04, FPMM,04, and FPNE,05, can each enter the solution without causing any other projects to forced out or following in. The results of this test reflects the tradeoffs for the feasible losers to become selected and in each case the scope of the problem is substantially reduced. For a project such as, FPSD,01, the tradeoff involves five previously selected projects. Therefore, instead of comparing FPSD,01 with every other project, the decision maker need only consider the merits of the five projects that leave the solution. This process enables the decision maker to more easily understand the complete dynamics of the problem. In the case of project, FPLK,02, the tradeoff involves only two previously selected projects. The decision maker can readily compare the merits of the loser with these two projects and determine a course of action.

Forced in Projects	# Projects Forced-out	# Losers Following in	Objective Function
FL6X,01	2	3	921.67
FL6X,02	2	3	921.67
FPHB,01	2	3	921.67
FPJB,06	0	0	920.50
FPLF,06	0	0	920.88
FPLG,02	0	0	919.74
FPLK,02	2	0	919.96
FPLK,04	0	0	921.06
FPMM,04	0	0	921.38
FPNB,01	2	0	960.72
FPNE,05	0	0	920.30
FPSD,01	5	1	1110.85
FPSD,04	5	2	1111.27
FPSD,06	5	1	1110.85

Table 12. Summary information after forcing in feasible losers one at a time. Five projects do not cause project to be either forced-out or to follow-in. They can individually be funded with the current budget profile.

The summary results of forcing in a group of feasible losers is shown in Table 13 with the complete results located in Appendix F. The previous analysis demonstrated that the three projects chosen are able to individually enter the solution. When all three are simultaneously forced-in, only one project is forced out of the solution. In this case, the value (warfighting value) of the project forced-out is only marginally better than the losers. Thus, the decision maker may decide to fund the three project option vice the one project option.

Forced in Projects	# Projects Forced-out	# Losers Following in	Objective Function
FPJB,06 FPLF,06 FPMM,04	1	0	924.28

Table 13. Summary information after forcing in a group of feasible projects. The one project forced-out has only a marginally better value than those forced-in, thus indicating a potentially desirable change.

F. BUDGET SENSITIVITY ANALYSIS

The most turbulent model parameter, budget level, is studied in this section. To demonstrate the versatility of the application of variable persistence, both feasible and infeasible budget profiles are investigated. An infeasible budget profile is defined as a profile that is not sufficient to fund all of the projects under consideration. The detailed analysis is presented in Appendix G. For each budget situation, three different models were solved: *Model 1*-RDA^3 with no changes except budget levels, *Model 2*-RDA^3 with the originally funded projects fixed, and *Model 3*-RDA^3 with a robust variable persistence applied. Summary results are shown in Tables 14 and 15.

Model	Total Budget Allocation	# Projects Forced-out of the solution	# Losers that Enter the Solution	% Total Budget Spent	Objective Function Value
Original RDA^3	$165 billion	n/a	n/a	95.89	919.63
1. Re-solved RDA^3	$135 billion	21	0	99.88	1044.55
2. Original Solution Fixed	$135 billion	0	0	100	1118.02
3. Persistence Applied	$135 billion	0	0	100	1118.02

Table 14. Summary of the budget sensitivity analysis with a feasible budget profile. Model 1, cause a wholesale change in funded projects, but achieves a better objective function value than Models 2 and 3.

Model	Total Budget Allocation	# Projects Forced-out of the solution	# Losers that Enter the Solution	% Total Budget Spent	Objective Function Value
Original RDA^3	$165 billion	n/a	n/a	95.89	919.63
1. Re-solved RDA^3	$120 billion	27	3	97.84	1060.41
2. Original Solution Fixed	$120 billion	n/a	n/a	n/a	Infeasible
3. Persistence Applied	$120 billion	1	0	100	1354.31

Table 15. Summary of the budget sensitivity analysis with an infeasible budget profile.

This study shows that Model 3 provides the same solution as Model 2 with a feasible budget profile (Table 14) and is more robust since it also provides a solution when Model 2 is infeasible (Table 15). The model of choice, Model 1 or Model 3, depends on the decision maker's priorities. As discussed previously, before the final decision has been made, the budget allocation is just another parameter of interest where sensitivity analysis can be applied. The projects have not been chosen and therefore, the model that provides the best objective function value may be the desired one. To maximize the objective function value, Model 1 is preferred for the sensitivity analysis, regardless of the budget situation. On the other hand, if the project selection has been made, and the budget profile changes, Model 3 is more suitable to for the conduct of sensitivity analysis. Model 3 minimizes change. Tables 14 and 15 show that when the budget profile changes Model 1 produces a wholesale change in project selection, whereas, change is minimized with Model 3. There is a tradeoff for minimizing change. In the infeasible budget profile scenario, further investigation shows that the funding turbulence under the Model 3 solution is worsened (Appendix G). This may be significantly outweighed by the decision maker's priorities and at worst provides him with options. The level of persistence applied could be reduced, thus allowing the decision maker to seek a balance between limiting change and achieving capital budgeting goals.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

RDA^3, by itself, is a useful decision tool. It rapidly assimilates data and provides an optimal mix of research projects and an optimal allocation of scarce research and development dollars. However, this may not be sufficient information to make a decision concerning billions of dollars. This study develops and implements a GAMS formulation, *Sensitivity Analysis for RDA^3*, that automatically investigates a great portion of the decision space. After running this program, the decision maker understands the tradeoffs involved with unfunded projects, and in some cases determines that some losers could in fact be funded. Policy decisions, which include the mandating of projects as well as the funding relationships (logical constraints), are thoroughly reviewed. For the baseline data in this study, most of the mandated projects gained credibility through this review, but there were a few that deserve further scrutiny. For those losers that are not funded due to conflicts in the funding relationships, a clear story is presented that articulates precisely what the conflicts are. In every case, the scope of the problem for each loser is dramatically reduced, thus allowing the decision maker to compare the merits of projects on a remarkably small scale.

Additionally, a manually directed sensitivity analysis of the budget is possible. In today's environment it is increasingly necessary to study the impact of sharp reductions in research and developments dollars. Sensitivity Analysis for RDA^3, provides a robust capability to accomplish this in a way that is consistent with the decision maker's priorities. The decision maker can maximize the achievement of his capital budgeting goals, minimize the change to the current set of research projects, or seek a balance between achievement and change.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

1. Development of a Graphical User Interface (GUI)

The development of a GUI for RDA^3 was proposed by Donahue (1992) and continues to be an obvious enhancement. Any enhancement that makes the process easier for the decision maker, as well as the analyst with no GAMS training, is desirable. An initial step towards the development of a GUI would be the integration of RDA^3 and Sensitivity Analysis for RDA^3 with a standard spreadsheet. Although the intent of this study is to make the sensitivity analysis as simple as possible, there is still the requirement for directions to be given in GAMS syntax.

2. Obtaining Project Effectiveness Coefficients

As discussed earlier, the methodology currently used to obtain the project effectiveness coefficients is the controversial Analytic Hierarchy Process (AHP). Another value assessment methodology based on elicitation procedures, such as SMARTS or SMARTER should be pursued (Edwards and Barron, 1994). Presently, research is underway to find another methodology at the Concepts Analysis Agency (CAA) (Loerch, 1995).

3. Implementation of a Heuristic to Isolate Overlapped IISs

This study implemented a strategy to find non-overlapped irreducible inconsistent sets. Since the existence of overlapped IISs is more prevalent, a heuristic designed to find as many of them as possible would be useful. If overlapped IISs exist, the first constraints identified by the elastic filter process should be members of overlapped IISs. This is because the objective of the elastic filter is to minimize the sum of the elastic variables that indicate infeasibility. Therefore, any constraint that is a member of more than one IIS should be discovered on the first pass of the elastic filter.

C. RELEVANCE TO THE ARMY

The usefulness of this study is directly linked to RDA^3's adoption as a capital budgeting tool for the United States Army. If DCSOPS decides to use RDA^3 in the development of the Army Modernization Plan, then the integration of *Sensitivity Analysis for* RDA^3 will substantially enhance the analysis. Otherwise, the Army should consider providing a similar automatic sensitivity analysis capability to whatever model is used. Further research and commitment to automating the analysis could potentially streamline the interactive process between decision makers and analysts, and accelerate the overall decision cycle.

APPENDIX A. GAMS FORMULATION

The GAMS formulation for *Sensitivity Analysis for RDA*^{3} is presented below.

```
$TITLE Sensitivity Analysis for RDA3
$onmixed offsymxref offsymlist offuellist
*-------------------------------------------------------------------------
*          Summary Report of the Losers List
*-------------------------------------------------------------------------
OPTIONS
   limrow    =      0
   limcol    =      0
   solprint  =    OFF
   mip       =     XA
   rmip      =     XA
   optcr     =    0.05
   optca     =      0
   iterlim   =  50000
   reslim    =  10000
   integer1  =    101
   integer2  =    122
   ;
*--------------------------------------------------------------------
$INCLUDE RDA3.OPT

ALIAS (I,II,III);
ALIAS (J,JJ,JJJ);
ALIAS(LLE,LLE1);
ALIAS(LEQ,LEQ1);

SET ELASTICNUM Loop index for number of logical equations /1*100/;
ALIAS(ELASTICNUM,IISNUM);

SET LOS(I,J) The original set of losers;
    LOS(IJ)=YES$(Z.L(IJ) EQ 0);

SET LOS1(I,J) The set of losers after unfunded MDEP forced in;
SET FORCEOUT(I,J) Set of increments that are forced out;
SET FOLLOWIN(I,J) Set of increments that follow a forced-in increment;

SET FEASIBLE(I,J) The set of losers that do not violate absolute constraints;
    FEASIBLE(IJ)=LOS(IJ);

SET INFEASIBLE(I,J) The set of losers that are infeasible due to ;
*                   constraint violations;
    INFEASIBLE(I,J)=NO;

SET MANDATED(I,J) The temporary set of mandated MDEPs that conflict with a given force
in;
    MANDATED(IJ)=NO;

SET MANDCON(I,J) The permanent set of all mandated MDEPs that conflict with a force
in;
    MANDCON(IJ)=NO;
```

```
SET INCIIS(I,J) The set of INCREMENT equations that are a part of an isolated IIS;
    INCIIS(IJ)=NO;

SET LLEIIS(LLE) The set of LOGCLE equations that are a part of an isolated IIS;
    LLEIIS(LLE)=NO;

SET LEQIIS(LEQ) The set of LOGCEQ equations that are a part of an isolated IIS;
    LEQIIS(LEQ)=NO;

SET MANIIS(I,J) The set of MANDATES equations that are a part of an isolated IIS;
    MANIIS(IJ)=NO;

SET MANON(I,J) MANDATES equation inclusion switch;
    MANON(IJ(I,J))$(TOTASPIRE(I,J) AND(MANDATE(I,J) EQ 1))= YES;

SET MANON2(I,J) Copy of MANON switch;
    MANON2(IJ)$MANON(IJ) = YES;

SET INCOFF(I,J) Set of INCREMENT equations turned off;
    INCOFF(IJ)= NO;

SET MANOFF(I,J) Set of MANDATE equations turned off;
    MANOFF(IJ)= NO;

SET LLEOFF(LLE) Set of LOGCLE equations turned off;
    LLEOFF(LLE)= NO;

SET LEQOFF(LEQ) Set of LOGCEQ equations turned off;
    LEQOFF(LEQ)= NO;

PARAMETERS
    XO1(I,J,T)  Original optimal value of X
    ZO1(I,J)  Original optimal value of Z
    NWARVALO1 Original optimal value of NWARVAL
    NBAL1O1   Original optimal value of NBAL
    NBAL2O1   Original optimal value of NBAL2
    PBAL1O1   Original optimal value of PBAL1
    PBAL2O1   Original optimal value of PBAL2
    NTURBO1   Original optimal value of NTURB
    DEVIATO1  Original optimal value of DEVIATION;

XO1(IJ,T)    = X.L(IJ,T);
ZO1(I,J)   = Z.L(I,J);

NWARVALO1 = SUM(T,NWARVAL.L(T));
NBAL1O1   = SUM((K,T),NBAL1.L(K,T));
NBAL2O1   = SUM((K,T),NBAL2.L(K,T));
PBAL1O1   = SUM((K,T),PBAL1.L(K,T));
PBAL2O1   = SUM((K,T),PBAL2.L(K,T));
NTURBO1   = SUM((IJ,T),NTURB.L(IJ,T));
DEVIATO1  = DEVIATION.L;

PARAMETERS
    NEWFUND Funding for un-mandated MDEP
    NEWPERC Percent funding for un-mandated MDEP
    ;

PARAMETERS
    COUNT    Global Counter
    FLAG     Global Flag
```

```
    TESTNUM  Counter for the number of the sensitivity test
    BUDGTNUM Counter for the number of the budget test
    LOGICNUM Counter for the number of the logical infeasible test
    LOGCFLAG Flag that indicates whether or not logical infeasibilities exist
    MANDNUM  Counter for the number of the mandate analysis
    FEASNUM  Counter for the number of the feasible test;

TESTNUM  = 0;
BUDGTNUM = 0;
LOGICNUM = 0;
MANDNUM  = 0;
FEASNUM  = 0;
COUNT    = 0;
LOGCFLAG = 0;
FLAG     = 0;

PARAMETERS
    TNWARVAL  Total negative warvalue deviation
    TNBAL1    Total negative balance deviation from desired
    TNBAL2    Total negative balance deviation from minimum
    TPBAL1    Total positive balance deviation from desired
    TPBAL2    Total positive balance deviation from maximum
    TNTURB    Total negative turbulence deviation
    TDEVIATION  Total deviation for model
    ;

  TNWARVAL = SUM(T,NWARVAL.L(T));
    TNBAL1 = SUM((K,T),NBAL1.L(K,T));
    TNBAL2 = SUM((K,T),NBAL2.L(K,T));
    TPBAL1 = SUM((K,T),PBAL1.L(K,T));
    TPBAL2 = SUM((K,T),PBAL2.L(K,T));
    TNTURB = SUM((IJ,T),NTURB.L(IJ,T));
TDEVIATION = DEVIATION.L;
*------------------------------------------------------------------
*For budget analysis

PARAMETERS
    NTOTFUN(i,j)        total funding allocated to
                        mdep increment
    NMISNFUN(k,t)       funding given to mission area by
                        fiscal year
    NTOTYEAF(t)         total funding by fiscal year
    NTOTYEAA(t)         total funding aspired by fiscal year
    NTOTMISF(k)         total funding given to mission area
    NTOTMISA(k)         total funding aspired by mission
                        area
    NTOTAS              total funding requested
    NTOTSPEN            total funding allocated
    NTOTBUDGE           total budget
    NFUNDPER(i,j,t)     percentage funded for each MDEP
    NFUNDMONE(i,j,t)    dollars Funded for each MDEP

    NPERCFUNA(I,J)    percentage of aspiration funded
    NPCTFUNM(K)       percentage of mission area aspiration
                      funded
    NPCTBUDGEM(K)     percentage of budget spent per mission
                      area
    NPCTALLOM(K)      percentage of funds spent allocated per
                      mission area
    NOVERALPCA        overall percentage of aspired funds spent
    NOVERALPCB        overall percentage of budget spent
```

```
    NPCTUNSPEB        percentage of budget that is unspent
    NSUMASPIR         sum of all aspired funds for MDEPs
    NSUMFUN           sum of all actual funds for MDEPs
    NPCTFUNA          percentage of aspired funds actually funded
    NSUMFUNW          total warvalue provided by funded MDEPs
    NSUMFUNO          total operating cost for funded MDEPs
    NEXCASPIR         total aspired for excluded MDEPs
    NEXCNU            number of excluded MDEPs
    NEXCWARVA         total warvalue for excluded MDEPs
    ;
*-------------------------------------------------------------------
*Output file settings

FILE LOST/LOST.DAT/;
PUT LOST;
LOST.PC= 3;
LOST.PW= 200;
LOST.ND= 2;
LOST.TM= 1;
LOST.PS= 55;
LOST.NJ= 2;
*-------------------------------------------------------------------
*Title
PUTTL SYSTEM.DATE,'  ',SYSTEM.TIME,@65,'Page ',SYSTEM.PAGE//
      @17,'AUTOMATIC SENSITIVITY ANALYSIS FOR RDA3'/
     @17,'_______________________________________'///;

PUT@5,'This program was developed by CPT Pete Johnson in partial'/
   @5,'fulfillment of the requirements for a Master of Science in'/
   @5,'Operations Research at the Naval Postgraduate School, Monterey,'/
   @5,'California.  His thesis advisor was Professor Richard E. Rosenthal.'/;

PUTPAGE;
LOST.TLLL= 0;
PUTTL SYSTEM.DATE,'  ',SYSTEM.TIME,@65,'Page ',SYSTEM.PAGE//;
*-------------------------------------------------------------------
*Check to see if a loser MDEP breaks the budget in any given year for
*either a 100% funding policy or a partial funding policy of mandated
*projects.

PARAMETER MANDCOST(T) lower bound on cost of mandated projects in year t ;

MANDCOST(T)   =  SUM((II,JJ) $ MANDATE(II,JJ),
                  ASPIRE(II,JJ,T) * (1$FULL+MINLEVYR(II,JJ)$(FULL EQ 0))) ;

PARAMETER MANDOSCOST  lower bound on oscost of mandated projects ;

MANDOSCOST   =  SUM( (II,JJ) $ MANDATE(II,JJ),
                OSCOST(II,JJ) * (1$FULL+MINLEVYR(II,JJ)$(FULL EQ 0))) ;

PARAMETER MANCOST  lower bound on cost of mandated projects if minlevel
*                  greater than minlevyr
;

MANCOST = SUM((II,JJ)$MANDATE(II,JJ),
              TOTASPIRE(II,JJ)*(1$FULL+MINLEVEL(II,JJ)$(FULL EQ 0)));

IF[LOGICAL OR FEASIBL OR GROUPFES,

TESTNUM=TESTNUM +1;
PUTHD '#',TESTNUM:<2:0,' Budget and OSCOST Feasibility Analysis'/
```

```
                     @5,'______________________________________'///;

PUT @5,'Budget profile: ';
LOOP[T,PUT @24,T.TL:<5:0,BUDGET(T):<20:0/;
]; {loop}
PUT/@5,'Maximum total OSCOST: ',@29,MAXOSCOST:<20:0//;

PUT   @5,'Result: ';

LOOP[(I,J)$FEASIBLE(I,J),
    IF[MINLEVYR(I,J) LT MINLEVEL(I,J),
    {then}
          IF[ ( MINLEVEL(I,J)*TOTASPIRE(I,J) + MANCOST
                   GT TOTBUDGET),
          {then}
              COUNT= COUNT + 1;
              BUDGTNUM$(COUNT EQ 1)= BUDGTNUM +1;

              PUT$(COUNT EQ 1) @14,BUDGTNUM:>2:0,'.';
              PUT$(COUNT EQ 1) @18,I.TE(I):27,I.TL:4,J.TL:2/
                  @18,'Violates the total budget constraint ';

              FEASIBLE(I,J)=NO;
              INFEASIBLE(I,J)=YES;
          ]; {if}
     ]; {if}

      LOOP[T,             {if true then violates the annual budget constraint}
          IF[ ( MINLEVYR(I,J)*ASPIRE(I,J,T) + MANDCOST(T)
                   GT BUDGET(T)),
          {then}
              COUNT= COUNT + 1;
              BUDGTNUM$(COUNT EQ 1)= BUDGTNUM +1;

              PUT$(COUNT EQ 1) @14,BUDGTNUM:>2:0,'.';
              PUT$(COUNT EQ 1) @18,I.TE(I):27,I.TL:4,J.TL:2/
                  @18,'Violates the budget constraint in year: ';
              PUT @60,T.TL/;

              FEASIBLE(I,J)=NO;
              INFEASIBLE(I,J)=YES;
          ]; {if}
      ]; {loop}



      IF[COUNT NE 0,
      {then}
         PUT//;
      ]; {if}
*-------------------------------------------------------------------
*check adherence to maximum OSCOST

        {if true then does not adhere to the maximum OSCOST}
    IF[ MANDOSCOST + OSCOST(I,J) * MAX(MINLEVYR(I,J),MINLEVEL(I,J))
           GT MAXOSCOST,
    {then}
        BUDGTNUM$(COUNT EQ 0)= BUDGTNUM +1;
        PUT$(COUNT EQ 0) @14,BUDGTNUM:>2:0,'.'
        PUT$(COUNT EQ 0) @18,I.TE(I):27,I.TL:4,J.TL:2/;
        PUT @18,'Does not adhere to the maximum operation and support costs.'//;
```

```
        FEASIBLE(I,J)=NO;
        INFEASIBLE(I,J)=YES;
    ]; {if}
    COUNT=0;
]; {loop}

LOOP[(I,J)$INFEASIBLE(I,J),
     COUNT=COUNT+1;
]; {loop}
IF[COUNT EQ 0, PUT @14,'All losers are budget and OSCOST feasible'//;
]; {if}

BUDGTNUM= 0; {re-initialize counter}
COUNT= 0; {re-initialize counter}
PUTPAGE;
LOST.HDLL= 0;

]; {logical or feasibl or groupfes}
*-------------------------------------------------------------------
*Develop a sub-model including only the logical constraints
*and the INCREMENT equations from RDA3.

VARIABLES
    ELASTICS Equal to sum of the elastic variables in sub-model
    ELASTIC  Objective function variable for sub-model;

POSITIVE VARIABLES
    MNINFES(I,J) Elastic variable accounting for negative infeasibility
    MPINFES(I,J) Elastic variable accounting for positive infeasibility;

EQUATIONS
    LOGICDEF1
    LOGICDEF
    MANDATES(I,J);

*Explicitly include the mandated variables as equations in the sub-model
*First relax the mandated variables

Z.LO(IJ(I,J))$(TOTASPIRE(I,J) AND (MANDATE(I,J) EQ 1))= 0;

MANDATES(IJ(I,J))$MANON(I,J)..
    Z(I,J)-MPINFES(I,J) +MNINFES(I,J)=E=1.0;

LOGICDEF1..ELASTICS=E=SUM(LLE,INFES(LLE))
                  +SUM(LEQ,PINFES(LEQ)+NINFES(LEQ))
                  +SUM(IJ(I,J)$((ORD(J) GT 1)$IJ(I,"01")),INCINFES(I,J))
                  +SUM(IJ(I,J),MNINFES(I,J) +MPINFES(I,J));

LOGICDEF..ELASTIC=E= ELASTICS +.01*SUM(IJ,Z(IJ));

MODEL LOSER/LOGICDEF,LOGICDEF1,INCREMENT,LOGCLE,LOGCEQ,MANDATES/;
           {submodel of all logical constraints}

MODEL DELETION/LOGICDEF,LOGICDEF1,INCREMENT,LOGCLE,LOGCEQ,MANDATES/;
           {submodel of all logical constraints}

*-------------------------------------------------------------------
*Initial bounds for the elastic variables

INFES.LO(LLE)=0;
```

```
PINFES.LO(LEQ)=0;
NINFES.LO(LEQ)=0;
INCINFES.LO(IJ)=0;
MNINFES.LO(IJ)=0;
MPINFES.LO(IJ)=0;

INFES.UP(LLE)=3;
PINFES.UP(LEQ)=3;
NINFES.UP(LEQ)=3;
INCINFES.UP(IJ)=3;
MNINFES.UP(IJ)=3;
MPINFES.UP(IJ)=3;
*-------------------------------------------------------------------
*Perform infeasibility test on all losers

IF[ LOGICAL,  {then}

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Logical Constraint Infeasibility Analysis'/
                      @5,'__________________________________________'///;
*-------------------------------------------------------------------
*Analyze each loser still feasible by forcing into the solution one at a time

  LOOP[(II,JJ)$FEASIBLE(II,JJ),

      Z.FX(II,JJ)=1.0;
      SOLVE LOSER USING MIP MINIMIZING ELASTIC;

        {infeasible if elastic variables have value}
   IF [ ELASTICS.L NE 0, {then}
       LOGICNUM= LOGICNUM +1;
       LOGCFLAG= 1.0;
       PUT @5,LOGICNUM:>2:0,'.';
       PUT @9,'Infeasible loser: ';
       PUT I.TE(II):27,II.TL:4,JJ.TL:2//;

       FEASIBLE(II,JJ)=NO;
       INFEASIBLE(II,JJ)=YES;
*-------------------------------------------------------------------
*Perform elastic filtering of the submodel LOSER
   LOOP[IISNUM$(ELASTICS.L NE 0),

         COUNT= COUNT +1.0;
         PUT @5,'Filter pass #',COUNT:<3:0/;
         PUT @9,'Constraints Violated: '//;

     LOOP[ ELASTICNUM$(LOSER.modelstat NE 4),

*Test the less than or equal to constraints for infeasibilities

        LOOP[ LLE$(INFES.L(LLE) NE 0),

           PUT @9,LLE.TL:7,', Fund either but not both: ';

           LOOP[(III,JJJ)$ALE(LLE,III,JJJ),
              PUT @42,I.TE(III):27,III.TL:4,JJJ.TL:2/;
              MANDATED(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
              MANDCON(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
           ]; {loop}
           PUT/;
```

```
           INFES.FX(LLE)=0;
           LLEIIS(LLE)=YES;
        ]; {loop}

*Test the equal to constraints for infeasibilties

         LOOP[ LEQ$((NINFES.L(LEQ) NE 0) OR (PINFES.L(LEQ) NE 0)),
             FLAG= 1;
             PUT @9,LEQ.TL:7,', Fund both or neither: ';

             LOOP[(III,JJJ)$AEQ(LEQ,III,JJJ),
                 PUT @38,I.TE(III):27,III.TL:4,JJJ.TL:2/;
                 MANDATED(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
                 MANDCON(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
             ]; {loop}

           NINFES.FX(LEQ)=0;
           PINFES.FX(LEQ)=0;
           LEQIIS(LEQ)=YES;
         ]; {loop}

           IF[FLAG, {then}
              PUT/;
           ]; {if}
           FLAG=0;

*Test the INCREMENT equations for infeasibilities

         LOOP[(III,JJJ)$(INCINFES.L(III,JJJ) NE 0),
             FLAG= 1;
             PUT  @9,'Must fund ',III.TL:4,"01 before "
                  I.TE(III):27,III.TL:4,JJJ.TL:2/;

             MANDATED(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
             MANDCON(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
             INCINFES.FX(III,JJJ)=0;
             INCIIS(III,JJJ)=YES;
         ]; {loop}

           IF[FLAG, {then}
              PUT/;
           ]; {if}
           FLAG=0;

*Test the MANDATES equations for infeasibilities

         LOOP[(III,JJJ)$((MNINFES.L(III,JJJ) NE 0) OR
                         (MPINFES.L(III,JJJ) NE 0)),
             FLAG=1;
             PUT @9,'Mandated: Must fund ',I.TE(III):27,III.TL:4,JJJ.TL:2/;
             MANDATED(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
             MANDCON(III,JJJ)$(MANDATE(III,JJJ) EQ 1)=YES;
             MNINFES.FX(III,JJJ)=0;
             MPINFES.FX(III,JJJ)=0;
             MANIIS(III,JJJ)=YES;
         ]; {loop}

           IF[FLAG, {then}
              PUT/;
           ]; {if}
           FLAG=0;
```

```
       SOLVE LOSER USING MIP MINIMIZING ELASTIC;

     ]; {loop, ELASTICNUM}

$ontext
     LOOP[(III,JJJ)$MANDATED(III,JJJ),

         PUT @9,'*Mandated: ',I.TE(III):27,III.TL:4,JJJ.TL:2/;
         MANDATED(III,JJJ)= NO;
     ]; {loop}
$offtext
*-------------------------------------------------------------------
* Apply the Deletion Filter
*Delete all the constraints from Model Loser except for those isolated by the
*elastic filter.

LOOP[(III,JJJ)$(NOT(INCIIS(III,JJJ))),
    INCON(III,JJJ)=NO;
]; {loop}

LOOP[(III,JJJ)$(NOT(MANIIS(III,JJJ))),
    MANON(III,JJJ)=NO;
]; {loop}

LOOP[LLE1$(NOT(LLEIIS(LLE1))),
    LLEON(LLE1)=NO;
]; {loop}

LOOP[LEQ1$(NOT(LEQIIS(LEQ1))),
    LEQON(LEQ1)=NO;
]; {loop}

*Remove constraints one at a time and test infeasibility

LOOP[(III,JJJ)$INCIIS(III,JJJ),
    INCON(III,JJJ)=NO;
    SOLVE DELETION USING MIP MINIMIZING ELASTIC;

    IF[DELETION.modelstat NE 4, {then}
        INCON(III,JJJ)=YES;
    ELSE
        INCIIS(III,JJJ)=NO;
    ]; {if}
]; {loop}

LOOP[(III,JJJ)$MANIIS(III,JJJ),
    MANON(III,JJJ)=NO;
    SOLVE DELETION USING MIP MINIMIZING ELASTIC;

    IF[DELETION.modelstat NE 4, {then}
        MANON(III,JJJ)=YES;
    ELSE
        MANIIS(III,JJJ)=NO;
    ]; {if}
]; {loop}

LOOP[(LLE1)$LLEIIS(LLE1),
    LLEON(LLE1)=NO;
    SOLVE DELETION USING MIP MINIMIZING ELASTIC;
```

```
    IF[DELETION.modelstat NE 4, {then}
       LLEON(LLE1)=YES;
    ELSE
       LLEIIS(LLE1)=NO;
    ]; {if}
];  {loop}

LOOP[(LEQ1)$LEQIIS(LEQ1),
    LEQON(LEQ1)=NO;
    SOLVE DELETION USING MIP MINIMIZING ELASTIC;

    IF[DELETION.modelstat NE 4, {then}
       LEQON(LEQ1)=YES;
    ELSE
       LEQIIS(LEQ1)=NO;
    ]; {if}
]; {loop}
*-------------------------------------------------------------------
*Restore original submodel constraints

INCON(III,JJJ)$(INCON2(III,JJJ) AND NOT(INCOFF(III,JJJ))) = YES;
MANON(III,JJJ)$(MANON2(III,JJJ) AND NOT(MANOFF(III,JJJ))) = YES;
LLEON(LLE1)$(NOT(LLEOFF(LLE1)))= YES;
LEQON(LEQ1)$(NOT(LEQOFF(LEQ1)))= YES;

*-------------------------------------------------------------------
*Output results of the deletion filter AND remove IIS from submodel

PUT /@9,'Irreducible inconsistent set (IIS):  '//;

LOOP[(III,JJJ)$INCIIS(III,JJJ),
    FLAG=1;
    PUT @9,'Must fund ',III.TL:4,"01 before "
        I.TE(III):27,III.TL:4,JJJ.TL:2/;
    INCON(III,JJJ)=NO;
    INCOFF(III,JJJ)= YES;
]; {loop}
   IF[FLAG, {then}
       PUT/;
   ]; {if}
   FLAG=0;

LOOP[(III,JJJ)$MANIIS(III,JJJ),
    FLAG=1;
    PUT @9,'Mandated: Must fund ',I.TE(III):27,III.TL:4,JJJ.TL:2/;
    MANON(III,JJJ)=NO;
    MANOFF(III,JJJ)= YES;
]; {loop}
   IF[FLAG, {then}
       PUT/;
   ]; {if}
   FLAG=0;

LOOP[ LLE$LLEIIS(LLE),
    PUT @9,'Fund either but not both: ';
    LOOP[(III,JJJ)$ALE(LLE,III,JJJ),
              PUT @35,I.TE(III):27,III.TL:4,JJJ.TL:2//;
    ]; {loop}
    LLEON(LLE)=NO;
    LLEOFF(LLE)= YES;
    PUT/;
```

```
]; {loop}

LOOP[ LEQ$LEQIIS(LEQ),
    PUT @9,'Fund both or neither: ';
    LOOP[(III,JJJ)$AEQ(LEQ,III,JJJ),
                 PUT @31,I.TE(III):27,III.TL:4,JJJ.TL:2//;
    ]; {loop}
    LEQON(LEQ)=NO;
    LEQOFF(LEQ)= YES;
    PUT/;
]; {loop}
*-------------------------------------------------------------------
*Re-initialize the elastic variable bounds

       INFES.LO(LLE)=0;
       PINFES.LO(LEQ)=0;
       NINFES.LO(LEQ)=0;
       INCINFES.LO(IJ)=0;
       MNINFES.LO(IJ)=0;
       MPINFES.LO(IJ)=0;

       INFES.UP(LLE)=3;
       PINFES.UP(LEQ)=3;
       NINFES.UP(LEQ)=3;
       INCINFES.UP(IJ)=3;
       MNINFES.UP(IJ)=3;
       MPINFES.UP(IJ)=3;

*Remove the identified IIS
       INCIIS(III,JJJ)=NO;
       MANIIS(III,JJJ)=NO;
       LLEIIS(LLE1)=NO;
       LEQIIS(LEQ1)=NO;
*-------------------------------------------------------------------
*Re-solve submodel to test for additional IISs

SOLVE LOSER USING MIP MINIMIZING ELASTIC;

]; {loop, IISNUM}
COUNT= 0;
*-------------------------------------------------------------------
*Re-initialize the dynamic sets
       INCIIS(III,JJJ)=NO;
       MANIIS(III,JJJ)=NO;
       LLEIIS(LLE1)=NO;
       LEQIIS(LEQ1)=NO;

       INCON(III,JJJ)$INCON2(III,JJJ) = YES;
       MANON(III,JJJ)$MANON2(III,JJJ)= YES;
       LLEON(LLE1)=YES;
       LEQON(LEQ1)=YES;
*-------------------------------------------------------------------
  ]; {if, ELASTICS NE 0}
  Z.LO(II,JJ)=0.0;
  PUT /;

  ]; {loop}

IF[NOT(LOGCFLAG), {then}
    PUT @9,'There are no logical infeasibilities in the model.';
]; {if}
```

```
PUTPAGE;
LOST.HDLL= 0;

]; {if logical}

*-------------------------------------------------------------------

*Take the elastic variables out of the model prior to executing
*further sensitivity analysis.

INFES.FX(LLE)=0;
PINFES.FX(LEQ)=0;
NINFES.FX(LEQ)=0;
INCINFES.FX(IJ)=0;
MNINFES.FX(IJ)=0;
MPINFES.FX(IJ)=0;

*Re-fix the mandated variables to 1
Z.FX(IJ(I,J))$MANDATE(I,J) =1.0;

*------------------ ------------------------------------------------
*Un-mandate mandated MDEPs that conflict in the logical constraints

IF[ CONFLICT, {then}

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Analysis of Mandated MDEPs that Conflict with Losers'/
                      @5,'____________________________________________________'///;

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVAL01,@43,NBAL101,@49,NBAL201,@55,PBAL101
    @61,PBAL201,@67,NTURB01,@73,TDEVIATION///;

  LOOP[(II,JJ)$MANDCON(II,JJ),
      MANDNUM= MANDNUM +1;
      Z.LO(II,JJ)=0;
      X.LO(II,JJ,T)=0.0;
      SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

      LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

      FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
      FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);
      FOLLOWIN(ii,jj) = no ;

      TNWARVAL = SUM(T,NWARVAL.L(T));
        TNBAL1 = SUM((K,T),NBAL1.L(K,T));
        TNBAL2 = SUM((K,T),NBAL2.L(K,T));
        TPBAL1 = SUM((K,T),PBAL1.L(K,T));
        TPBAL2 = SUM((K,T),PBAL2.L(K,T));
        TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
    TDEVIATION = DEVIATION.L;

 PUT MANDNUM:>2:0,'.','Un-mandate:  '@28,' MDEP ',@35,'NWARVAL',@43,'NBAL1'
     @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
     @28,'______'@35,'_______',@43,'_____',@49,'_____'
```

```
       @55,'______'@61,'______',@67,'______',@73,'__________'/;

         PUT I.TE(II):27,II.TL:4,JJ.TL:2,@35,TNWARVAL,@43,TNBAL1
          @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION//;

       LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
          COUNT= COUNT +1;
          FLAG= 1;

          PUT$(COUNT EQ 1) @60,'War-value'/@60,'__________'/;
          PUT$(COUNT EQ 1) @5,'Forced out: ';
          PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;

       ]; {loop}
          COUNT=0;

          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;

       LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
          COUNT=  COUNT + 1;
          FLAG= 1;
          PUT$(COUNT EQ 1) @60,'War-value'/@60,'__________'/;
          PUT$(COUNT EQ 1) @5,'     Enter: ';
          PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;

       ]; {loop}
          COUNT=0;

          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;

       NEWFUND=SUM(T,X.L(II,JJ,T)*ASPIRE(II,JJ,T));
       NEWPERC=100*NEWFUND/TOTASPIRE(II,JJ);

       IF[NOT(FORCEOUT(II,JJ)),
           PUT/@5,'Funding change for mandate: ';
           PUT @34,I.TE(II):27,II.TL:4,JJ.TL:2/;
           PUT @34,'Before: ',TOTFUND(II,JJ):<14:0,@54,PERCFUNDA(II,JJ):>6:2,'%'/
               @34,' After: ',NEWFUND:<14:0,@54,NEWPERC:>6:2,'%'/;
       ]; {if}

      Z.LO(II,JJ)=1.0;
      X.LO(II,JJ,T)=1.0;
      PUT /;

  ]; {loop}

LOST.HDLL= 0;
PUTPAGE;

]; {if conflict}
MANDNUM=0;
*----------------------------------------------------------------------
*Un-mandate all originally mandated MDEPs one at a time

IF[ ALLMAND, {then}
```

```
TESTNUM= TESTNUM +1;
PUTHD '#',TESTNUM:<2:0,' Analysis of All Mandated MDEPs '/
                     @5,'__________________________________'///;

 PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
   @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
   @61,'_____',@67,'_____',@73,'_________'/;

 PUTHD  'RDA3  RESULTS',@35,NWARVAL01,@43,NBAL101,@49,NBAL201,@55,PBAL101
   @61,PBAL201,@67,NTURB01,@73,DEVIAT01///;

 LOOP[(II,JJ)$(TOTASPIRE(II,JJ) AND  (MANDATE(II,JJ) EQ 1)),

     MANDNUM= MANDNUM +1;
     Z.LO(II,JJ)=0;
     X.LO(II,JJ,T)=0.0;
     SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

     LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

     FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
     FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);
     FOLLOWIN(ii,jj) = NO;

     TNWARVAL = SUM(T,NWARVAL.L(T));
       TNBAL1 = SUM((K,T),NBAL1.L(K,T));
       TNBAL2 = SUM((K,T),NBAL2.L(K,T));
       TPBAL1 = SUM((K,T),PBAL1.L(K,T));
       TPBAL2 = SUM((K,T),PBAL2.L(K,T));
       TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
   TDEVIATION = DEVIATION.L;

PUT MANDNUM:>2:0,'.','Un-mandate:  '@28,' MDEP ',@35,'NWARVAL',@43,'NBAL1'
    @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @28,'______'@35,'_______',@43,'_____',@49,'_____'
    @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;

      PUT I.TE(II):27,II.TL:4,JJ.TL:2,@35,TNWARVAL,@43,TNBAL1
       @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION//;

    LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
       COUNT= COUNT +1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'Forced out: ';
       PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

    LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
       COUNT=  COUNT + 1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'     Enter: ';
```

```
          PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
       ]; {loop}
          COUNT=0;

          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;

       NEWFUND=SUM(T,X.L(II,JJ,T)*ASPIRE(II,JJ,T));
       NEWPERC=100*NEWFUND/TOTASPIRE(II,JJ);

       IF[NOT(FORCEOUT(II,JJ)),
           PUT/@5,'Funding change for mandate: ';
           PUT @35,I.TE(II):27,II.TL:4,JJ.TL:2/;
           PUT @35,'Before: ',TOTFUND(II,JJ):<14:0,@54,PERCFUNDA(II,JJ):>6:2,'%'/
               @35,' After: ',NEWFUND:<14:0,@54,NEWPERC:>6:2,'%'/;
       ]; {if}

      Z.LO(II,JJ)=1.0;
      X.LO(II,JJ,T)=1.0;
      PUT /;

  ]; {loop}

LOST.HDLL= 0;
PUTPAGE;

]; {if allmand}

MANDNUM=0;
*---------------------------------------------------------------------
*Un-mandate a group of mandated MDEPs

IF[ GROUPMAN, {then}

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Analysis of a Specified Group of Mandated MDEPs '/
                      @5,'_______________________________________________'///;

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVAL01,@43,NBAL101,@49,NBAL201,@55,PBAL101
    @61,PBAL201,@67,NTURB01,@73,DEVIAT01///;

  LOOP[(II,JJ)$MANGRP(II,JJ),

      Z.LO(II,JJ)=0;
      X.LO(II,JJ,T)=0.0;
  ]; {loop}

      SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

      LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

      FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
      FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);
```

```
    LOOP[(II,JJ)$MANGRP(II,JJ),
        FOLLOWIN(II,JJ) = NO;
    ]; {loop}

    TNWARVAL = SUM(T,NWARVAL.L(T));
      TNBAL1 = SUM((K,T),NBAL1.L(K,T));
      TNBAL2 = SUM((K,T),NBAL2.L(K,T));
      TPBAL1 = SUM((K,T),PBAL1.L(K,T));
      TPBAL2 = SUM((K,T),PBAL2.L(K,T));
      TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
  TDEVIATION = DEVIATION.L;

PUT 'Group Un-Mandated Result: ',@28,' MDEP ',@35,'NWARVAL'
    @43,'NBAL1',@49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB'
    @73,'DEVIATION'/
    @28,'______'@35,'_______',@43,'_____',@49,'_____'
    @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;

  LOOP[(II,JJ)$MANGRP(II,JJ),
      COUNT = COUNT + 1;
      PUT$(COUNT EQ 1) @35,TNWARVAL,@43,TNBAL1
       @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION//;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;

      PUT COUNT:>2:0,'. ',I.TE(II):27,II.TL:4,JJ.TL:2,@60,WARVAL(II,JJ);
      PUT/;
  ]; {loop}
      COUNT = 0;
      PUT/;

    LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
       COUNT= COUNT +1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'Forced out: ';
       PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

    LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
       COUNT=  COUNT + 1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'     Enter: ';
       PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

LOOP[(II,JJ)$MANGRP(II,JJ),

   NEWFUND=SUM(T,X.L(II,JJ,T)*ASPIRE(II,JJ,T));
```

```
      NEWPERC=100*NEWFUND/TOTASPIRE(II,JJ);

      IF[NOT(FORCEOUT(II,JJ)),
          PUT/@5,'Funding change for mandate: ';
          PUT @35,I.TE(II):27,II.TL:4,JJ.TL:2/;
          PUT @35,'Before: ',TOTFUND(II,JJ):<14:0,@54,PERCFUNDA(II,JJ):>6:2,'%'/
              @35,' After: ',NEWFUND:<14:0,@54,NEWPERC:>6:2,'%'/;
      ]; {if}
   ]; {loop}

  LOOP[(II,JJ)$MANGRP(II,JJ),
     Z.LO(II,JJ)=1.0;
     X.LO(II,JJ,T)=1.0;
  ]; {loop}

LOST.HDLL= 0;
PUTPAGE;

]; {if groupman}

MANDNUM=0;
*------------------------------------------------------------------
*Summary report of the Losers

IF[GROUPMAN, {then}

 PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                      @5,'_________________'///;

PUTHD 'MDEP TITLE',@28,'MDEP/INC',@38,'TOT-ASPIRED',@51,'WAR-VALUE'/;
PUTHD '__________',@28,'________',@38,'___________',@51,'_________'/;

LOOP[IJ(II,JJ)$(Z.L(II,JJ) EQ 0),
            PUT @1,I.TE(II),@28,II.TL:4,JJ.TL:<2:0,@38,TOTASPIRE(II,JJ):<10:0
                @51,WARVAL(II,JJ):<5:2/;
]; {loop}

PUTPAGE;
LOST.HDLL=0;
]; {if groupman}
*------------------------------------------------------------------
*Force the feasible MDEPs into the solution one at a time

IF[ FEASIBL, {then}

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Analysis of Feasible Losers '/
                      @5,'___________________________'///;

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVALO1,@43,NBAL1O1,@49,NBAL2O1,@55,PBAL1O1
    @61,PBAL2O1,@67,NTURBO1,@73,DEVIATO1///;

  LOOP[(II,JJ)$FEASIBLE(II,JJ),
      FEASNUM= FEASNUM + 1;
      Z.FX(II,JJ)=1.0;
      SOLVE RDA3 MINIMIZING DEVIATION USING MIP;
```

```
 IF[RDA3.modelstat NE 4, {then}

    LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

    FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
    FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);
    FOLLOWIN(II,JJ) = NO;

    TNWARVAL = SUM(T,NWARVAL.L(T));
      TNBAL1 = SUM((K,T),NBAL1.L(K,T));
      TNBAL2 = SUM((K,T),NBAL2.L(K,T));
      TPBAL1 = SUM((K,T),PBAL1.L(K,T));
      TPBAL2 = SUM((K,T),PBAL2.L(K,T));
      TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
  TDEVIATION = DEVIATION.L;
PUT/;
PUT FEASNUM:>2:0,'.','Force-in:  '@28,' MDEP ',@35,'NWARVAL',@43,'NBAL1'
    @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @28,'______'@35,'_______',@43,'_____',@49,'_____'
    @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;

      PUT I.TE(II):<28:0,II.TL:4,JJ.TL:2,@35,TNWARVAL,@43,TNBAL1
       @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION//;


    LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
       COUNT= COUNT +1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'Forced out: ';
       PUT  @18,I.TE(III):<28:0,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

    LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
       COUNT=  COUNT + 1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @4,'Followed-in: ';
       PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

 ELSE
        FEASIBLE(II,JJ)=NO;
        INFEASIBLE(II,JJ)=YES;
 ]; {if}

  Z.LO(II,JJ)=0.0;
  PUT /;
```

```
  ]; {loop}

LOST.HDLL= 0;
PUTPAGE;

]; {if feasibl}

FEASNUM=0;
*-------------------------------------------------------------------
*Force in a group of feasible MDEPs into the solution at the same time

IF[ GROUPFES, {then}

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Analysis of a Specified Group of Feasible Losers '/
                      @5,'________________________________________________'///;

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'________',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVALO1,@43,NBAL1O1,@49,NBAL2O1,@55,PBAL1O1
    @61,PBAL2O1,@67,NTURBO1,@73,DEVIATO1///;

  LOOP[(II,JJ)$FEASGRP(II,JJ),
      Z.FX(II,JJ)=1.0;
  ]; {loop}

      SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

   IF[RDA3.modelstat NE 4, {then}

      LOOP[(II,JJ)$FEASGRP(II,JJ),
          FEASIBLE(II,JJ)= YES;
      ]; {loop}

      LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

      FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
      FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);

   LOOP[(II,JJ)$FEASGRP(II,JJ),
      FOLLOWIN(II,JJ) = NO;
   ]; {loop}

      TNWARVAL = SUM(T,NWARVAL.L(T));
        TNBAL1 = SUM((K,T),NBAL1.L(K,T));
        TNBAL2 = SUM((K,T),NBAL2.L(K,T));
        TPBAL1 = SUM((K,T),PBAL1.L(K,T));
        TPBAL2 = SUM((K,T),PBAL2.L(K,T));
        TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
    TDEVIATION = DEVIATION.L;

  PUT 'Group Force-in Result:  '@28,' MDEP ',@35,'NWARVAL'
      @43,'NBAL1',@49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB'
      @73,'DEVIATION'/
      @28,'_____'@35,'_______',@43,'_____',@49,'_____'
      @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;
```

```
     LOOP[(II,JJ)$FEASGRP(II,JJ),
         COUNT = COUNT + 1;
         PUT$(COUNT EQ 1) @35,TNWARVAL,@43,TNBAL1
          @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION//;
          PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
         PUT COUNT:>3:0,'. ',I.TE(II):27,II.TL:4,JJ.TL:2,@60,WARVAL(II,JJ);
         PUT/;
     ]; {loop}
         COUNT = 0;
         PUT/;

       LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
          COUNT= COUNT +1;
          FLAG= 1;
          PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
          PUT$(COUNT EQ 1) @5,'Forced out: ';
          PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
       ]; {loop}
          COUNT=0;

          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;

       LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
          COUNT=  COUNT + 1;
          FLAG= 1;
          PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
          PUT$(COUNT EQ 1) @4,'Followed-in: ';
          PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
       ]; {loop}
          COUNT=0;

          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;

    ELSE
      LOOP[(II,JJ)$FEASGRP(II,JJ),
          FEASIBLE(II,JJ)=NO;
          INFEASIBLE(II,JJ)=YES;
      ]; {loop}
    ]; {if}

    LOOP[(II,JJ)$FEASGRP(II,JJ),
     Z.LO(II,JJ)=0.0;
    ]; {loop}

     PUT /;

LOST.HDLL= 0;
PUTPAGE;

]; {if groupfes}

FEASNUM=0;
*-------------------------------------------------------------------
*Summary report of the Losers
```

```
IF[GROUPFES, {then}

 PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                      @5,'_________________'///;

PUTHD 'MDEP TITLE',@28,'MDEP/INC',@38,'TOT-ASPIRED',@51,'WAR-VALUE'/;
PUTHD '__________',@28,'________',@38,'___________',@51,'_________'/;

LOOP[IJ(II,JJ)$(Z.L(II,JJ) EQ 0),
            PUT @1,I.TE(II),@28,II.TL:4,JJ.TL:<2:0,@38,TOTASPIRE(II,JJ):<10:0
                @51,WARVAL(II,JJ):<5:2/;
]; {loop}

PUTPAGE;
LOST.HDLL=0;
]; {if groupfes}

*-------------------------------------------------------------------

*Budget analysis, BEFORE decision

IF[BUDGETB, {then}

OPTION Integer2 = 0;

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Budget Analysis Before Decision '/
                      @5,'________________________________'///;

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVALO1,@43,NBAL1O1,@49,NBAL2O1,@55,PBAL1O1
    @61,PBAL2O1,@67,NTURBO1,@73,DEVIATO1///;

  BUDGET(T)$ALTBUDGET(T) = ALTBUDGET(T);

  SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

  IF[RDA3.modelstat NE 4, {then}

*New parameter values

NTOTFUN(IJ)       =  SUM( t, X.L(IJ,t) * ASPIRE(IJ,t) ) ;
NMISNFUN(k,t)     =  SUM( IJ $ MSNAREA(IJ,k), X.L(IJ,t) *
                     ASPIRE(IJ,t) ) ;
NTOTYEAF(t)       =  SUM( k, NMISNFUN(k,t) ) ;
NTOTYEAA(t)       =  SUM( IJ, ASPIRE(IJ,t) ) ;
NTOTMISF(k)       =  SUM( t, NMISNFUN(k,t) ) ;
NTOTMISA(k)       =  SUM( IJ $ MSNAREA(IJ,k), TOTASPIRE(IJ) ) ;
NTOTAS            =  SUM( k, NTOTMISA(k) ) ;
NTOTSPEN          =  SUM( k, NTOTMISF(k) ) ;
NTOTBUDGE         =  SUM( t, BUDGET(t) ) ;
NFUNDPER(IJ,T)    =  X.L(IJ,T) * 100.0 ;
NFUNDMONE(IJ,T) = NFUNDPER(IJ,T) * ASPIRE(IJ,T)/100;

NPERCFUNA(IJ(I,J)) = 100*NTOTFUN(I,J)/TOTASPIRE(I,J);
NPCTFUNM(K)        = (100*NTOTMISF(k)/NTOTMISA(k))$(NTOTMISA(K) NE 0);
NPCTBUDGEM(K)      = 100*NTOTMISF(k)/NTOTBUDGE;
```

```
NPCTALLOM(K)       = 100*NTOTMISF(k)/NTOTSPEN;
NOVERALPCA         = (100*NTOTSPEN/NTOTAS)$(NTOTAS NE 0);
NOVERALPCB         = 100*NTOTSPEN/NTOTBUDGE;
NPCTUNSPEB         = 100-NOVERALPCB;
NSUMASPIR          = SUM(IJ,TOTASPIRE(IJ));
NSUMFUN            = SUM(IJ,NTOTFUN(IJ));
NPCTFUNA           = 100*SUM(IJ,NTOTFUN(IJ))/SUM(IJ,TOTASPIRE(IJ));
NSUMFUNW           = SUM(IJ$NTOTFUN(IJ),WARVAL(IJ));
NSUMFUNO           = SUM(IJ$NTOTFUN(IJ),OSCOST(IJ));
NEXCASPIR          = SUM(EXC,TOTASPIRE(EXC));
NEXCNU             = CARD(EXC);
NEXCWARVA          = SUM(EXC,WARVAL(EXC));

      LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

      FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
      FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);

      TNWARVAL = SUM(T,NWARVAL.L(T));
        TNBAL1 = SUM((K,T),NBAL1.L(K,T));
        TNBAL2 = SUM((K,T),NBAL2.L(K,T));
        TPBAL1 = SUM((K,T),PBAL1.L(K,T));
        TPBAL2 = SUM((K,T),PBAL2.L(K,T));
        TNTURB = SUM((I,J,T),NTURB.L(I,J,T));
    TDEVIATION = DEVIATION.L;

  PUT @35,'NWARVAL',@43,'NBAL1'
      @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
      @35,'_______',@43,'_____',@49,'_____'
      @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;

        PUT 'New results: ',@35,TNWARVAL,@43,TNBAL1
         @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION///;

        PUT @5,'Budget profile: ';
        LOOP[T,PUT @24,T.TL:<5:0,ALTBUDGET(T):<20:0/;
        ]; {loop}
        PUT///;

      LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
         COUNT= COUNT +1;
         FLAG= 1;
         PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
         PUT$(COUNT EQ 1) @5,'Forced out: ';
         PUT  @18,I.TE(III):<28:0,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
      ]; {loop}
         COUNT=0;

         IF[FLAG, {then}
            PUT/;
         ]; {if}
         FLAG= 0;

      LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
         COUNT=  COUNT + 1;
         FLAG= 1;
         PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
         PUT$(COUNT EQ 1) @5,'     Enter: ';
         PUT  @18,I.TE(III):<28:0,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
      ]; {loop}
         COUNT=0;
```

```
          IF[FLAG, {then}
             PUT/;
          ]; {if}
          FLAG= 0;
      LOST.HDLL=0;
      PUTPAGE;
      PUTHD ///
      'MDEP TITLE',@28,'MDEP/INC',@46,'TOTASPIRED'
      @57,'TOTFUND',@66,'PCT-FUNDED'/

      '__________',@28,'________',@46,'__________',@57,'_______'
      @66,'__________'/;

     LOOP(IJ(I,J),
        PUT$(TOTFUND(I,J)) @1,I.TE(I):<28:0,@28,I.TL:4,J.TL:<2:0,@35,'old--> '
          @46,TOTASPIRE(I,J):<10:0,@57,TOTFUND(I,J):<10:0
          @66,PERCFUNDA(I,J):<6:2/;
        PUT$FOLLOWIN(I,J) @1,I.TE(I):<28:0,@28,I.TL:4,J.TL:<2:0,@35,'old--> '
          @46,'-Not funded-'/;

        PUT @35,'new--> '
        PUT$(NTOTFUN(I,J)) @46,TOTASPIRE(I,J):<10:0,@57,NTOTFUN(I,J):<10:0
          @66,NPERCFUNA(I,J):<6:2//;
        PUT$FORCEOUT(I,J) @46,'-Not funded-'//;

     );
     PUT '__________________________________________________________________'
         '__________________'/;
     PUT 'TOTALS:',@9,'old--> ',@18,'% of Budget: ',OVERALPCTB:<6:2
         @46,SUMASPIRE:<9:2,@56,SUMFUND:<9:2,@66,PCTFUNDA:<6:2/;
     PUT @9,'new--> ',@18,'% of Budget: ',NOVERALPCB:<6:2
         @46,NSUMASPIR:<9:2,@56,NSUMFUN:<9:2,@66,NPCTFUNA:<6:2/;

  ELSE PUT @5,'Infeasible budget level'/;
  ]; {if}

LOST.HDLL= 0;
PUTPAGE;

]; {if budgetb}
*---------------------------------------------------------------------
*Summary report of the Losers

IF[BUDGETB, {then}

 PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                      @5,'_________________'///;

PUTHD 'MDEP TITLE',@28,'MDEP/INC',@38,'TOT-ASPIRED',@51,'WAR-VALUE'/;
PUTHD '_________',@28,'________',@38,'___________',@51,'_________'/;

LOOP[IJ(II,JJ)$(Z.L(II,JJ) EQ 0),
            PUT @1,I.TE(II),@28,II.TL:4,JJ.TL:<2:0,@38,TOTASPIRE(II,JJ):<10:0
                @51,WARVAL(II,JJ):<5:2/;
]; {loop}

PUTPAGE;
LOST.HDLL=0;
]; {if budgetb}
```

```
*-------------------------------------------------------------------

*Formulation of a model that encourages old variable values to remain the same

FREE VARIABLE DEVIAT2 The original RDA3 objective function plus the sum
*                     of the weighted persistence deviations;

POSITIVE VARIABLES
    ZPOS(I,J)   Accounts for positive deviation in Z variables
    ZNEG(I,J)   Accounts for negative deviation in Z variables;

SCALARS
    WPOS   Penalty for positive deviation in Z variables
    WNEG   Penalty for negative deviation in Z variables
    ALPHA  Level of persistence;

*Variable bounds
    ZPOS.LO(IJ)=0;
    ZPOS.UP(IJ)=1.0;
    ZNEG.LO(IJ)=0;
    ZNEG.UP(IJ)=1.0;

*Set weights and level of persistence
    WPOS=1;
    WNEG=20;
    ALPHA=.9;

* formulation of objective

EQUATIONS
    VARPERSIS(I,J) Variable persistence equation
    OBJDEF2 Objective function;

VARPERSIS(IJ(I,J))..Z(I,J)=E= ZO1(I,J)+ZPOS(I,J)-ZNEG(I,J);

OBJDEF2..      (1-ALPHA)*( SUM(t, WEIGHT1(t) * NWARVAL(t))
                     +  SUM((k,t), WEIGHT2(t) * NBAL1(k,t))
                     +  SUM((k,t), WEIGHT3(t) * NBAL2(k,t))
                     +  SUM((k,t), WEIGHT2(t) * PBAL1(k,t))
                     +  SUM((k,t), WEIGHT3(t) * PBAL2(k,t))
                     +  SUM((IJ,t) $ (ASPIRE(IJ,t) * ASPIRE(IJ,t-1)),
                            WEIGHT4(t) * NTURB(IJ,t)) / SCALTURB)
                     +SUM(IJ,ALPHA*WPOS*ZPOS(IJ))
                     +SUM(IJ,ALPHA*WNEG*ZNEG(IJ))
                                       =E= DEVIAT2 ;

      MODEL PERSIST/WARVALUE,BALANCE,TURBULENCE,MODCOST,SUSTAIN
                    LINKAGE,FRACFUND,INCREMENT,{YRMIN,}LOGCLE,LOGCEQ
                    OBJDEF2,VARPERSIS/;
*-------------------------------------------------------------------
*Budget analysis, AFTER decision is made AND using persistence to
*encourage original projects to stay in the solution

IF[BUDGETA, {then}

OPTION INTEGER2 = 0;

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Budget Analysis After Decision (with persistence)'/
                      @5,'______________________________'///;
```

```
  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVAL01,@43,NBAL101,@49,NBAL201,@55,PBAL101
    @61,PBAL201,@67,NTURB01,@73,DEVIAT01///;

  BUDGET(T)$ALTBUDGET(T) = ALTBUDGET(T);

  SOLVE PERSIST MINIMIZING DEVIAT2 USING MIP;

  IF[PERSIST.modelstat NE 4, {then}

*New parameter values

NTOTFUN(IJ)       =  SUM( t, X.L(IJ,t) * ASPIRE(IJ,t) ) ;
NMISNFUN(k,t)     =  SUM( IJ $ MSNAREA(IJ,k), X.L(IJ,t) *
                     ASPIRE(IJ,t) ) ;
NTOTYEAF(t)       =  SUM( k, NMISNFUN(k,t) ) ;
NTOTYEAA(t)       =  SUM( IJ, ASPIRE(IJ,t) ) ;
NTOTMISF(k)       =  SUM( t, NMISNFUN(k,t) ) ;
NTOTMISA(k)       =  SUM( IJ $ MSNAREA(IJ,k), TOTASPIRE(IJ) ) ;
NTOTAS            =  SUM( k, NTOTMISA(k) ) ;
NTOTSPEN          =  SUM( k, NTOTMISF(k) ) ;
NTOTBUDGE         =  SUM( t, BUDGET(t) ) ;
NFUNDPER(IJ,T)    =  X.L(IJ,T) * 100.0 ;
NFUNDMONE(IJ,T) = NFUNDPER(IJ,T) * ASPIRE(IJ,T)/100;

NPERCFUNA(IJ(I,J)) = 100*NTOTFUN(I,J)/TOTASPIRE(I,J);
NPCTFUNM(K)        = (100*NTOTMISF(k)/NTOTMISA(k))$(NTOTMISA(K) NE 0);
NPCTBUDGEM(K)      = 100*NTOTMISF(k)/NTOTBUDGE;
NPCTALLOM(K)       = 100*NTOTMISF(k)/NTOTSPEN;
NOVERALPCA         = (100*NTOTSPEN/NTOTAS)$(NTOTAS NE 0);
NOVERALPCB         = 100*NTOTSPEN/NTOTBUDGE;
NPCTUNSPEB         = 100-NOVERALPCB;
NSUMASPIR          = SUM(IJ,TOTASPIRE(IJ));
NSUMFUN            = SUM(IJ,NTOTFUN(IJ));
NPCTFUNA           = 100*SUM(IJ,NTOTFUN(IJ))/SUM(IJ,TOTASPIRE(IJ));
NSUMFUNW           = SUM(IJ$NTOTFUN(IJ),WARVAL(IJ));
NSUMFUNO           = SUM(IJ$NTOTFUN(IJ),OSCOST(IJ));
NEXCASPIR          = SUM(EXC,TOTASPIRE(EXC));
NEXCNU             = CARD(EXC);
NEXCWARVA          = SUM(EXC,WARVAL(EXC));

     LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

     FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
     FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);

     TNWARVAL = SUM(T,NWARVAL.L(T));
       TNBAL1 = SUM((K,T),NBAL1.L(K,T));
       TNBAL2 = SUM((K,T),NBAL2.L(K,T));
       TPBAL1 = SUM((K,T),PBAL1.L(K,T));
       TPBAL2 = SUM((K,T),PBAL2.L(K,T));
       TNTURB = SUM((I,J,T),NTURB.L(I,J,T));


   TDEVIATION = (DEVIAT2.L-SUM(IJ,ALPHA*WPOS*ZPOS.L(IJ))
                 -SUM(IJ,ALPHA*WNEG*ZNEG.L(IJ)))/(1-ALPHA)   ;
```

```
PUT @35,'NWARVAL',@43,'NBAL1'
    @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____'
    @55,'_____'@61,'_____',@67,'______',@73,'_________'/;

      PUT 'New results: ',@35,TNWARVAL,@43,TNBAL1
       @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION///;

      PUT @5,'Budget profile: ';
      LOOP[T,PUT @24,T.TL:<5:0,ALTBUDGET(T):<20:0/;
      ]; {loop}
      PUT///;

    LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
       COUNT= COUNT +1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'Forced out: ';
       PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;

    LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
       COUNT=  COUNT + 1;
       FLAG= 1;
       PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
       PUT$(COUNT EQ 1) @5,'     Enter: ';
       PUT @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
    ]; {loop}
       COUNT=0;

       IF[FLAG, {then}
          PUT/;
       ]; {if}
       FLAG= 0;
  LOST.HDLL=0;
  PUTPAGE;
  PUTHD ///
  'MDEP TITLE',@28,'MDEP/INC',@46,'TOTASPIRED'
  @57,'TOTFUND',@66,'PCT-FUNDED'/

  '__________',@28,'________',@46,'__________',@57,'_______'
  @66,'__________'/;

 LOOP(IJ(I,J),
    PUT$(TOTFUND(I,J)) @1,I.TE(I):<28:0,@28,I.TL:4,J.TL:<2:0,@35,'old--> ',@46
      TOTASPIRE(I,J):<10:0,@57,TOTFUND(I,J):<10:0
      @66,PERCFUNDA(I,J):<6:2/;
    PUT$FOLLOWIN(I,J) @1,I.TE(I):<28:0,@28,I.TL:4,J.TL:<2:0,@35,'old--> '@46
      '-Not funded-'/;

    PUT @35,'new--> '
    PUT$(NTOTFUN(I,J)) @46,TOTASPIRE(I,J):<10:0,@57,NTOTFUN(I,J):<10:0
      @66,NPERCFUNA(I,J):<6:2//;
    PUT$FORCEOUT(I,J) @46,'-Not funded-'//;
```

```
      );
      PUT '____________________________________________________________'
          '_________________'/;

      PUT 'TOTALS:',@9,'old--> ',@18,'% of Budget: ',OVERALPCTB:<6:2
           @46,SUMASPIRE:<9:2,@56,SUMFUND:<9:2,@66,PCTFUNDA:<6:2/;
      PUT @9,'new--> ',@18,'% of Budget: ',NOVERALPCB:<6:2
           @46,NSUMASPIR:<9:2,@56,NSUMFUN:<9:2,@66,NPCTFUNA:<6:2/;

    ELSE PUT @5,'Infeasible budget level'/;
    ]; {if}

  LOST.HDLL= 0;
  PUTPAGE;

  ]; {if budgeta}
  *--------------------------------------------------------------------
  *Summary report of the Losers

  IF[BUDGETA, {then}

   PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                       @5,'_________________'///;

  PUTHD 'MDEP TITLE',@28,'MDEP/INC',@38,'TOT-ASPIRED',@51,'WAR-VALUE'/;
  PUTHD '__________',@28,'________',@38,'___________',@51,'_________'/;

  LOOP[IJ(II,JJ)$(Z.L(II,JJ) EQ 0),
              PUT @1,I.TE(II),@28,II.TL:4,JJ.TL:<2:0,@38,TOTASPIRE(II,JJ):<10:0
                  @51,WARVAL(II,JJ):<5:2/;
  ]; {loop}

  PUTPAGE;
  LOST.HDLL=0;
  ]; {if budgeta}

  *--------------------------------------------------------------------
  *Budget analysis, AFTER decision is made AND fixing the original solution

  IF[BUDGETA2, {then}

  OPTION INTEGER2 = 0;

   TESTNUM= TESTNUM +1;
   PUTHD '#',TESTNUM:<2:0,' Budget Analysis After Decision (old solution fixed)'/
                       @5,'______________________________'///;

       LOOP[IJ(I,J)$(ZO1(I,J) EQ 1),
            Z.FX(I,J)=1.0;
       ]; {loop}

    BUDGET(T)$ALTBUDGET(T) = ALTBUDGET(T);
    TOTBUDGET= SUM(T$ALTBUDGET(T), ALTBUDGET(T));
  *--------------------------------------------------------------------
  *Check to see if a loser MDEP breaks the budget in any given year for
  *either a 100% funding policy or a partial funding policy of mandated
  *projects.

  MANDCOST(T)   =   SUM((II,JJ) $ MANDATE(II,JJ),
                     ASPIRE(II,JJ,T) * (1$FULL+MINLEVYR(II,JJ)$(FULL EQ 0))) ;
```

```
MANDOSCOST  =  SUM( (II,JJ) $ MANDATE(II,JJ),
                 OSCOST(II,JJ) * (1$FULL+MINLEVYR(II,JJ)$(FULL EQ 0))) ;

MANCOST = SUM((II,JJ)$MANDATE(II,JJ),
               TOTASPIRE(II,JJ)*(1$FULL+MINLEVEL(II,JJ)$(FULL EQ 0)));

TESTNUM=TESTNUM +1;
PUTHD '#',TESTNUM:<2:0,' Budget and OSCOST Feasibility Analysis (for budget
analysis)'/
                     @5,'_____________________________________'///;

PUT @5,'Budget profile: ';
LOOP[T,PUT @24,T.TL:<5:0,BUDGET(T):<20:0/;
]; {loop}
PUT/@5,'Maximum total OSCOST: ',@29,MAXOSCOST:<20:0//;

PUT   @5,'Result: ';

    LOOP[T,             {if true then violates the annual budget constraint}
          IF[ SUM((I,J)$(ZO1(I,J) AND NOT(MANDATE(I,J))),
                ASPIRE(I,J,T)*MINLEVYR(I,J)) +MANDCOST(T)
                GT BUDGET(T),
          {then}
              COUNT= COUNT + 1;
              BUDGTNUM$(COUNT EQ 1)= BUDGTNUM +1;

              PUT$(COUNT EQ 1) @14,BUDGTNUM:>2:0,'.';
              PUT$(COUNT EQ 1) @18,'Violates the budget constraint in year: ';
              PUT @60,T.TL/;

              FEASIBLE(I,J)=NO;
              INFEASIBLE(I,J)=YES;
          ]; {if}
    ]; {loop}

      IF[COUNT NE 0,
      {then}
         PUT//;
      ]; {if}

      IF[
          SUM((I,J)$(ZO1(I,J) AND NOT(MANDATE(I,J))),
           MINLEVEL(I,J)*TOTASPIRE(I,J)) + MANCOST
                   GT TOTBUDGET,
          {then}
              COUNT= COUNT + 1;
              BUDGTNUM$(COUNT EQ 1)= BUDGTNUM +1;

              PUT$(COUNT EQ 1) @14,BUDGTNUM:>2:0,'.';
              PUT$(COUNT EQ 1) @18,'Violates the total budget constraint ';

              FEASIBLE(I,J)=NO;
              INFEASIBLE(I,J)=YES;
          ]; {if}

      IF[COUNT NE 0,
      {then}
         PUT//;
      ]; {if}
*-----------------------------------------------------------------
*check adherence to maximum OSCOST
```

```
        {if true then does not adhere to the maximum OSCOST}
    IF[SUM((I,J)$(ZO1(I,J) AND NOT(MANDATE(I,J))),
                 OSCOST(I,J) * MINLEVYR(I,J)) + MANDOSCOST
           GT MAXOSCOST,
    {then}
        BUDGTNUM$(COUNT EQ 0)= BUDGTNUM +1;
        PUT$(COUNT EQ 0) @14,BUDGTNUM:>2:0,'.'
        PUT$(COUNT EQ 0)
        PUT @18,'Does not adhere to the maximum operation and support costs.'//;

        FEASIBLE(I,J)=NO;
        INFEASIBLE(I,J)=YES;
    ]; {if}
    COUNT=0;

LOOP[(I,J)$INFEASIBLE(I,J),
     COUNT=COUNT+1;
]; {loop}
IF[COUNT EQ 0, PUT @14,'The original solution is budget and OSCOST feasible'//;
]; {if}

BUDGTNUM= 0; {re-initialize counter}
COUNT= 0; {re-initialize counter}
PUTPAGE;
LOST.HDLL= 0;
*-------------------------------------------------------------------

  PUTHD @35,'NWARVAL',@43,'NBAL1',@49,'NBAL2',@55,'PBAL1'
    @61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
    @35,'_______',@43,'_____',@49,'_____',@55,'_____'
    @61,'_____',@67,'_____',@73,'_________'/;

  PUTHD  'RDA3  RESULTS',@35,NWARVALO1,@43,NBAL1O1,@49,NBAL2O1,@55,PBAL1O1
    @61,PBAL2O1,@67,NTURBO1,@73,DEVIATO1///;

  SOLVE RDA3 MINIMIZING DEVIATION USING MIP;

  IF[RDA3.modelstat NE 4, {then}

*New parameter values

NTOTFUN(IJ)       =  SUM( t, X.L(IJ,t) * ASPIRE(IJ,t) ) ;
NMISNFUN(k,t)     =  SUM( IJ $ MSNAREA(IJ,k), X.L(IJ,t) *
                     ASPIRE(IJ,t) ) ;
NTOTYEAF(t)       =  SUM( k, NMISNFUN(k,t) ) ;
NTOTYEAA(t)       =  SUM( IJ, ASPIRE(IJ,t) ) ;
NTOTMISF(k)       =  SUM( t, NMISNFUN(k,t) ) ;
NTOTMISA(k)       =  SUM( IJ $ MSNAREA(IJ,k), TOTASPIRE(IJ) ) ;
NTOTAS            =  SUM( k, NTOTMISA(k) ) ;
NTOTSPEN          =  SUM( k, NTOTMISF(k) ) ;
NTOTBUDGE         =  SUM( t, BUDGET(t) ) ;
NFUNDPER(IJ,T)    =  X.L(IJ,T) * 100.0 ;
NFUNDMONE(IJ,T)  = NFUNDPER(IJ,T) * ASPIRE(IJ,T)/100;

NPERCFUNA(IJ(I,J)) = 100*NTOTFUN(I,J)/TOTASPIRE(I,J);
NPCTFUNM(K)        = (100*NTOTMISF(k)/NTOTMISA(k))$(NTOTMISA(K) NE 0);
NPCTBUDGEM(K)      = 100*NTOTMISF(k)/NTOTBUDGE;
NPCTALLOM(K)       = 100*NTOTMISF(k)/NTOTSPEN;
NOVERALPCA         = (100*NTOTSPEN/NTOTAS)$(NTOTAS NE 0);
NOVERALPCB         = 100*NTOTSPEN/NTOTBUDGE;
```

```
NPCTUNSPEB         = 100-NOVERALPCB;
NSUMASPIR          = SUM(IJ,TOTASPIRE(IJ));
NSUMFUN            = SUM(IJ,NTOTFUN(IJ));
NPCTFUNA           = 100*SUM(IJ,NTOTFUN(IJ))/SUM(IJ,TOTASPIRE(IJ));
NSUMFUNW           = SUM(IJ$NTOTFUN(IJ),WARVAL(IJ));
NSUMFUNO           = SUM(IJ$NTOTFUN(IJ),OSCOST(IJ));
NEXCASPIR          = SUM(EXC,TOTASPIRE(EXC));
NEXCNU             = CARD(EXC);
NEXCWARVA          = SUM(EXC,WARVAL(EXC));

      LOS1(IJ)=YES$(Z.L(IJ) EQ 0);

      FORCEOUT(IJ)=LOS1(IJ)- LOS(IJ);
      FOLLOWIN(IJ)=LOS(IJ)-LOS1(IJ);

      TNWARVAL = SUM(T,NWARVAL.L(T));
        TNBAL1 = SUM((K,T),NBAL1.L(K,T));
        TNBAL2 = SUM((K,T),NBAL2.L(K,T));
        TPBAL1 = SUM((K,T),PBAL1.L(K,T));
        TPBAL2 = SUM((K,T),PBAL2.L(K,T));
        TNTURB = SUM((I,J,T),NTURB.L(I,J,T));

     TDEVIATION = DEVIATION.L;

  PUT @35,'NWARVAL',@43,'NBAL1'
      @49,'NBAL2',@55,'PBAL1'@61,'PBAL2',@67,'NTURB',@73,'DEVIATION'/
      @35,'_______',@43,'_____',@49,'_____'
      @55,'_____'@61,'_____',@67,'_____',@73,'_________'/;

        PUT 'New results: ',@35,TNWARVAL,@43,TNBAL1
         @49,TNBAL2,@55,TPBAL1,@61,TPBAL2,@67,TNTURB,@73,TDEVIATION///;
$ONTEXT
        PUT @5,'Budget profile: ';
        LOOP[T,PUT @24,T.TL:<5:0,ALTBUDGET(T):<20:0/;
        ]; {loop}
        PUT///;
$OFFTEXT
      LOOP[(III,JJJ)$FORCEOUT(III,JJJ),
         COUNT= COUNT +1;
         FLAG= 1;
         PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
         PUT$(COUNT EQ 1) @5,'Forced out: ';
         PUT  @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
      ]; {loop}
         COUNT=0;

         IF[FLAG, {then}
            PUT/;
         ]; {if}
         FLAG= 0;

      LOOP[(III,JJJ)$FOLLOWIN(III,JJJ),
         COUNT=  COUNT + 1;
         FLAG= 1;
         PUT$(COUNT EQ 1) @60,'War-value'/@60,'_________'/;
         PUT$(COUNT EQ 1) @5,'     Enter: ';
         PUT @18,I.TE(III):27,III.TL:4,' ',JJJ.TL:2,@60,WARVAL(III,JJJ)/;
      ]; {loop}
         COUNT=0;

         IF[FLAG, {then}
```

```
            PUT/;
        ]; {if}
        FLAG= 0;
    LOST.HDLL=0;
    PUTPAGE;
    PUTHD ///
    'MDEP TITLE',@28,'MDEP/INC',@46,'TOTASPIRED'
    @57,'TOTFUND',@66,'PCT-FUNDED'/

    '__________',@28,'________',@46,'__________',@57,'_______'
    @66,'__________'//;

   LOOP(IJ(I,J),
      PUT$(TOTFUND(I,J)) @1,I.TE(I):<27,@28,I.TL:4,J.TL:<2:0,@35,'old--> ',@46
        TOTASPIRE(I,J):<10:0,@57,TOTFUND(I,J):<10:0
        @66,PERCFUNDA(I,J):<6:2/;
      PUT$FOLLOWIN(I,J) @1,I.TE(I):<29,@28,I.TL:4,J.TL:<2:0,@35,'old--> '@46
        '-Not funded-'/;

      PUT @35,'new--> '
      PUT$(NTOTFUN(I,J)) @46,TOTASPIRE(I,J):<10:0,@57,NTOTFUN(I,J):<10:0
        @66,NPERCFUNA(I,J):<6:2//;
      PUT$FORCEOUT(I,J) @46,'-Not funded-'//;

   );
   PUT '____________________________________________________________'
       '__________________'/;

   PUT 'TOTALS:',@9,'old--> ',@18,'% of Budget: ',OVERALPCTB:<6:2
        @46,SUMASPIRE:<9:2,@56,SUMFUND:<9:2,@66,PCTFUNDA:<6:2/;
   PUT @9,'new--> ',@18,'% of Budget: ',NOVERALPCB:<6:2
        @46,NSUMASPIR:<9:2,@56,NSUMFUN:<9:2,@66,NPCTFUNA:<6:2/;

    LOOP[IJ(I,J)$(Z.L(I,J) EQ 1),
        Z.LO(I,J)= 0;
        Z.UP(I,J)= 1.0;
    ]; {loop}

    ELSE PUT @5,'Infeasible budget level'/;
    ]; {if}

LOST.HDLL= 0;
PUTPAGE;

]; {if budgeta}
*-----------------------------------------------------------------------

*Summary report of the Losers

IF[BUDGETA2, {then}

 PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                        @5,'_________________'///;

PUTHD 'MDEP TITLE',@28,'MDEP/INC',@38,'TOT-ASPIRED',@51,'WAR-VALUE'/;
PUTHD '__________',@28,'________',@38,'___________',@51,'_________'/;

LOOP[IJ(II,JJ)$(Z.L(II,JJ) EQ 0),
             PUT @1,I.TE(II),@28,II.TL:4,JJ.TL:<2:0,@38,TOTASPIRE(II,JJ):<10:0
                 @51,WARVAL(II,JJ):<5:2/;
]; {loop}
```

```
LOST.HDLL=0;
PUTPAGE;

]; {if budgeta2}

*------------------------------------------------------------------
SCALAR
    BUDGETWT;

BUDGETWT=0.4;

POSITIVE VARIABLES
    NBUDGET(T) Negative deviation from the annual budget level
    ;

FREE VARIABLE
    DEVIAT3 Sum of all the weighted goal deviations;

EQUATIONS
    OBJDEF3       Objective function
    COSTGOAL(T)   Budget goal;

COSTGOAL(T)..SUM((IJ),X(IJ,T)*ASPIRE(IJ,T))/BUDGET(T)=E=1-NBUDGET(T);
*VARPERSIS(IJ(I,J))..Z(I,J)=E= ZO1(I,J)+ZPOS(I,J)-ZNEG(I,J);


OBJDEF3..                SUM(t, WEIGHT1(t) * NWARVAL(t))
                      +  SUM((k,t), WEIGHT2(t) * NBAL1(k,t))
                      +  SUM((k,t), WEIGHT3(t) * NBAL2(k,t))
                      +  SUM((k,t), WEIGHT2(t) * PBAL1(k,t))
                      +  SUM((k,t), WEIGHT3(t) * PBAL2(k,t))
                      +  SUM((IJ,t) $ (ASPIRE(IJ,t) * ASPIRE(IJ,t-1)),
                             WEIGHT4(t) * NTURB(IJ,t)) / SCALTURB
                      +  SUM(T,BUDGETWT*NBUDGET(T))
                      =E= DEVIAT3 ;

      MODEL MAXBUDGET/WARVALUE,BALANCE,TURBULENCE,COSTGOAL,SUSTAIN
                     LINKAGE,FRACFUND,INCREMENT,{YRMIN,}LOGCLE,LOGCEQ
                     OBJDEF3/;

*------------------------------------------------------------------

IF[LOGICAL OR FEASIBL, {then}

*Summary of infeasible and feasible  Losers

 TESTNUM= TESTNUM +1;
 PUTHD '#',TESTNUM:<2:0,' Summary of Losers'/
                       @5,'_________________'///;

  PUT /'Summary list of infeasible MDEPs'/
       '________________________________'/;
    LOOP[(II,JJ)$INFEASIBLE(II,JJ),
        PUT I.TE(II):27,II.TL:4,' ',JJ.TL:2/
    ]; {loop}

  PUT/'Summary list of feasible MDEPs'/
      '______________________________'/;
    LOOP[(II,JJ)$FEASIBLE(II,JJ),
        PUT I.TE(II):27,II.TL:4,' ',JJ.TL:2/
```

```
    ]; {loop}
]; {if}
PUTCLOSE LOST;
```

APPENDIX B. OPTION FILE

This appendix presents the option file that directs the scope of the sensitivity analysis.

```
*Option file for RDA3

* 1 = yes   0 = no
*----------------------------------------------------------
*RDA3 model options

PARAMETER  FULL  Indicate 100% funding OR partial funding of mandates;
           FULL= 1;
*----------------------------------------------------------
*Sensitivity analysis options

PARAMETERS

 LOGICAL  Perform infeasibility screening with submodel of logical constraints
CONFLICT  Un-mandate mandated MDEPs that conflict in the logical constraints
 ALLMAND  Un-mandate all originally mandated MDEPs and solve
GROUPMAN  Un-mandate groups of mandated MDEPs and solve
 FEASIBL  Force-in each feasible loser or all losers if LOGICAL not performed
*            one at a time
GROUPFES  Force-in a group of feasible MDEPs at one time and solve
BUDGETB   Analyze effect of changes in annual budget levels BEFORE decision
BUDGETA   Analyze effect of changes in annual budget levels AFTER decision
BUDGETA2  Analyze effect of changes in annual budget levels AFTER decision
    ;

 LOGICAL=  1;
CONFLICT=  1;
 ALLMAND=  1;
GROUPMAN=  0;
 FEASIBL=  1;
GROUPFES=  0;
 BUDGETB=  0;
 BUDGETA=  0;
BUDGETA2=  0;
*----------------------------------------------------------
*Unmandate a group of mandated MDEPs

*Instruction: indicate desired group by assigning to set MANGRP as shown
*             below

SET MANGRP(I,J) group of mandated MDEPs;
*   MANGRP("FPJC","01")= YES;   **EXAMPLE**
*   MANGRP("FPSA","06")= YES;   **EXAMPLE**
*   add group below example  *
    MANGRP("FPEL","05")= YES;
    MANGRP("FPSA","01")= YES;
    MANGRP("FPSA","06")= YES;
    MANGRP("FPSB","01")= YES;
```

```
*-----------------------------------------------------------
*Force-in a group of feasible MDEPs

*Instruction: indicate desired group by assigning to set FEASGRP as shown
*             below

SET FEASGRP(I,J) group of feasible MDEPs;
*   FEASGRP("FPLF","06")= YES;   **EXAMPLE**
    FEASGRP("FPLF","06")= YES;
    FEASGRP("FPJB","06")= YES;
    FEASGRP("FPMM","04")= YES;
*-----------------------------------------------------------
*Change annual budget levels for analysis
*Budget in thousands of dollars

PARAMETER ALTBUDGET(T) An alternative budget allocation for analysis;

    ALTBUDGET("FY94")= 8000000;
    ALTBUDGET("FY95")= 8000000;
    ALTBUDGET("FY96")= 8000000;
    ALTBUDGET("FY97")= 8000000;
    ALTBUDGET("FY98")= 8000000;
    ALTBUDGET("FY99")= 8000000;
    ALTBUDGET("FY00")= 8000000;
    ALTBUDGET("FY01")= 8000000;
    ALTBUDGET("FY02")= 8000000;
    ALTBUDGET("FY03")= 8000000;
    ALTBUDGET("FY04")= 8000000;
    ALTBUDGET("FY05")= 8000000;
    ALTBUDGET("FY06")= 8000000;
    ALTBUDGET("FY07")= 8000000;
    ALTBUDGET("FY08")= 8000000;

*-----------------------------------------------------------
*Original budget levels
$ONTEXT
    ALTBUDGET("FY94")= 10000000;
    ALTBUDGET("FY95")= 10000000;
    ALTBUDGET("FY96")= 10000000;
    ALTBUDGET("FY97")= 10000000;
    ALTBUDGET("FY98")= 10000000;
    ALTBUDGET("FY99")= 11000000;
    ALTBUDGET("FY00")= 11000000;
    ALTBUDGET("FY01")= 11000000;
    ALTBUDGET("FY02")= 11000000;
    ALTBUDGET("FY03")= 11000000;
    ALTBUDGET("FY04")= 12000000;
    ALTBUDGET("FY05")= 12000000;
    ALTBUDGET("FY06")= 12000000;
    ALTBUDGET("FY07")= 12000000;
    ALTBUDGET("FY08")= 12000000;
$OFFTEXT
*-----------------------------------------------------------
```

APPENDIX C. LOGICAL CONSTRAINTS

This appendix presents the original formulation and the generic formulation of the logical constraints for comparison.

A. ORIGINAL FORMULATION OF THE LOGICAL CONSTRAINTS

```
* logical constraints

     EQUATIONS

         EXCLUSIV1                 don't fund mutually exclusive MDEPs
         EXCLUSIV2                 don't fund mutually exclusive MDEPs
         EXCLUSIV3                 don't fund mutually exclusive MDEPs
         EXCLUSIV4                 don't fund mutually exclusive MDEPs
         EXCLUSIV5                 don't fund mutually exclusive MDEPs

         SUB1                      don't fund mutually exclusive MDEP subsets
         SUB2                      don't fund mutually exclusive MDEP subsets
         SUB3                      don't fund mutually exclusive MDEP subsets
         SUB4                      don't fund mutually exclusive MDEP subsets
         SUB5                      don't fund mutually exclusive MDEP subsets

         COMP1                     fund complementary MDEPs
         COMP2                     fund complementary MDEPs
         COMP3                     fund complementary MDEPs
         COMP4                     fund complementary MDEPs
         COMP5                     fund complementary MDEPs
         COMP6                     fund complementary MDEPs
         COMP7                     fund complementary MDEPs
         COMP8                     fund complementary MDEPs
         COMP9                     fund complementary MDEPs
         COMP10                    fund complementary MDEPs
         COMP11                    fund complementary MDEPs
         COMP12                    fund complementary MDEPs
         COMP13                    fund complementary MDEPs
         COMP14                    fund complementary MDEPs
         COMP15                    fund complementary MDEPs
         COMP16                    fund complementary MDEPs
         COMP17                    fund complementary MDEPs
         COMP18                    fund complementary MDEPs
         COMP19                    fund complementary MDEPs
         ;


     * formulation of logical constraints

     *   don't fund mutually exclusive MDEPs

         EXCLUSIV1..      Z("FPHB","01") + Z("FPSG","01") =L= 1.0 ;
```

```
    EXCLUSIV2..      Z("FPSF","01") + Z("RF08","01") =L= 1.0 ;

    EXCLUSIV3..        Z("FPSB","01") + Z("FPSJ","01")
                     + Z("RA09","01") =L= 1.0 ;

    EXCLUSIV4..        Z("FPSD","01") + Z("FPNB","01")
                     + Z("FPDC","01") =L= 1.0 ;

    EXCLUSIV5..        Z("FPXX","01") + Z("FPLK","02")
                     + Z("FPSD","01") =L= 1.0 ;

*   don't fund mutually exclusive MDEP subsets

    SUB1..           Z("FPEA","01") =E= Z("FPEL","02") ;
    SUB2..           Z("FPEA","01") =E= Z("FPEL","05") ;
    SUB3..           Z("FPEA","01") + Z("FPGA","01") =L= 1.0 ;

    SUB4..           Z("FPSA","01") =E= Z("FPSA","06") ;
    SUB5..           Z("FPSA","01") + Z("FPSE","01") =L= 1.0 ;

*   fund complementary MDEPs

    COMP1..          Z("FPSG","01") =E= Z("FPSH","01") ;

    COMP2..          Z("FPHB","01") =E= Z("FL6X","01") ;

    COMP3..          Z("RA08","01") =E= Z("FPSE","01") ;
    COMP4..          Z("RA08","01") =E= Z("RF01","01") ;
    COMP5..          Z("RA08","01") =E= Z("RF08","01") ;

    COMP6..          Z("FPLF","01") =E= Z("FPFL","01") ;
    COMP7..          Z("FPLF","01") =E= Z("FPHC","01") ;
    COMP8..          Z("FPLF","01") =E= Z("FPLG","01") ;
    COMP9..          Z("FPLF","01") =E= Z("FPLX","01") ;
    COMP10..         Z("FPLF","01") =E= Z("FPLC","01") ;
    COMP11..         Z("FPLF","01") =E= Z("FPJA","01") ;

    COMP12..         Z("FPEA","01") =E= Z("FPED","01") ;
    COMP13..         Z("FPEA","01") =E= Z("FPEE","01") ;
    COMP14..         Z("FPEA","01") =E= Z("FPLE","01") ;

    COMP15..         Z("FPFP","01") =E= Z("FPWB","01") ;
    COMP16..         Z("FPFP","01") =E= Z("FPFL","01") ;
    COMP17..         Z("FPFP","01") =E= Z("FPFK","01") ;
    COMP18..         Z("FPFP","01") =E= Z("FPFB","01") ;
    COMP19..         Z("FPFP","01") =E= Z("FPWC","01") ;
```

B. GENERIC FORMULATION OF THE LOGICAL CONSTRAINTS

```
*Logical constraints

     SETS
         LLE logical constraints (less than or equal)
         /EXC1*EXC5,SUB3,SUB5/
```

```
         LEQ logical constraints (equal to)
         /SUB1,SUB2,SUB4,COMP1*COMP19/;

     SET INCON(I,J) increment inclusion switch;
         INCON(IJ(I,J))$(IJ(I,"01") AND ORD(J) GT 1)= YES;

     SET INCON2(I,J) Copy of INCON switch;
         INCON2(IJ)$INCON(IJ) = YES;

     SET LLEON(LLE) logcle inclusion switch;
         LLEON(LLE)=YES;

     SET LEQON(LEQ) logceq inclusion switch;
         LEQON(LEQ)=YES;

     PARAMETER ALE(LLE,I,J) coefficients of less than logical constraints
         /EXC1.FPHB.01    1
          EXC1.FPSG.01    1
          EXC2.FPSF.01    1
          EXC2.RF08.01    1
          EXC3.FPSB.01    1
          EXC3.FPSJ.01    1
          EXC3.RA09.01    1
          EXC4.FPSD.01    1
          EXC4.FPNB.01    1
          EXC4.FPDC.01    1
          EXC5.FPXX.01    1
          EXC5.FPLK.02    1
          EXC5.FPSD.01    1
          SUB3.FPEA.01    1
          SUB3.FPGA.01    1
          SUB5.FPSA.01    1
          SUB5.FPSE.01    1
           /;
     PARAMETER BLE(LLE) RHS of logical constraints (less than or equal)
         /EXC1*EXC5    1
          SUB3         1
          SUB5         1/;

     PARAMETER AEQ(LEQ,I,J) coefficients of equal to logical constraints
         /SUB1.FPEA.01     1
          SUB1.FPEL.02    -1
          SUB2.FPEA.01     1
          SUB2.FPEL.05    -1
          SUB4.FPSA.01     1
          SUB4.FPSA.06    -1
          COMP1.FPSG.01    1
          COMP1.FPSH.01   -1
          COMP2.FPHB.01    1
          COMP2.FL6X.01   -1
          COMP3.RA08.01    1
          COMP3.FPSE.01   -1
          COMP4.RA08.01    1
          COMP4.RF01.01   -1
          COMP5.RA08.01    1
          COMP5.RF08.01   -1
          COMP6.FPLF.01    1
          COMP6.FPFL.01   -1
          COMP7.FPLF.01    1
          COMP7.FPHC.01   -1
          COMP8.FPLF.01    1
```

```
      COMP8.FPLG.01   -1
      COMP9.FPLF.01    1
      COMP9.FPLX.01   -1
      COMP10.FPLF.01   1
      COMP10.FPLC.01  -1
      COMP11.FPLF.01   1
      COMP11.FPJA.01  -1
      COMP12.FPEA.01   1
      COMP12.FPED.01  -1
      COMP13.FPEA.01   1
      COMP13.FPEE.01  -1
      COMP14.FPEA.01   1
      COMP14.FPLE.01  -1
      COMP15.FPFP.01   1
      COMP15.FPWB.01  -1
      COMP16.FPFP.01   1
      COMP16.FPFL.01  -1
      COMP17.FPFP.01   1
      COMP17.FPFK.01  -1
      COMP18.FPFP.01   1
      COMP18.FPFB.01  -1
      COMP19.FPFP.01   1
      COMP19.FPWC.01  -1
       /;

PARAMETER BEQ(LEQ) RHS of logical constraints (equal to)
    /SUB1   0
     SUB2   0
     SUB4   0
    COMP1*COMP19    0/;

POSITIVE VARIABLES
    INFES(LLE) Elastic variable accounting for infeasibility in LLE
    PINFES(LEQ) Elastic variable accounting for positive infeasibility
    NINFES(LEQ) Elastic variable accounting for negative infeasibility
    INCINFES(I,J) Elastic variable accounting for infeasibility in INCREMENT;

EQUATIONS
    LOGCLE(LLE) logical constraints (less than or equal)
    LOGCEQ(LEQ) logical constraints (equal to)
    ;

LOGCLE(LLE)$(LLEON(LLE))..
    SUM(IJ,ALE(LLE,IJ)*Z(IJ))-INFES(LLE)=L=BLE(LLE);

LOGCEQ(LEQ)$(LEQON(LEQ))..
    SUM(IJ,AEQ(LEQ,IJ)*Z(IJ))-PINFES(LEQ)+NINFES(LEQ)=E=BEQ(LEQ);

INFES.FX(LLE)=0;
PINFES.FX(LEQ)=0;
NINFES.FX(LEQ)=0;
INCINFES.FX(I,J)=0;
```

APPENDIX D. BASELINE SOLUTION REPORTS

The results of the automatic sensitivity analysis for the baseline data are presented in this appendix.

A. BUDGET AND OSCOST ANALYSIS

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:     FY94 10000000
                        FY95 10000000
                        FY96 10000000
                        FY97 10000000
                        FY98 10000000
                        FY99 11000000
                        FY00 11000000
                        FY01 11000000
                        FY02 11000000
                        FY03 11000000
                        FY04 12000000
                        FY05 12000000
                        FY06 12000000
                        FY07 12000000
                        FY08 12000000

    Maximum total OSCOST:    999999999

    Result:  All losers are budget and OSCOST feasible
```

B. SUMMARY OF LOSERS

This summary is the finale of the automatic analysis and is presented up front here for the reader's benefit.

```
#6  Summary of Losers
        _________________
```

```
Summary list of infeasible MDEPs
________________________________
FPGA                       FPGA 01
FPGA                       FPGA 02
FPSE                       FPSE 01
FPSE                       FPSE 02
FPSJ                       FPSJ 01
RA08                       RA08 01
RA08                       RA08 06
RA09                       RA09 01
RA09                       RA09 02
RF01                       RF01 01
RF08                       RF08 01

Summary list of feasible MDEPs
______________________________
FL6X                       FL6X 01
FL6X                       FL6X 02
FPHB                       FPHB 01
FPJB                       FPJB 06
FPLF                       FPLF 06
FPLG                       FPLG 02
FPLK                       FPLK 02
FPLK                       FPLK 04
FPMM                       FPMM 04
FPNB                       FPNB 01
FPNE                       FPNE 05
FPSD                       FPSD 01
FPSD                       FPSD 04
FPSD                       FPSD 06
```

C. LOGICAL INFEASIBILITY ANALYSIS

```
#2  Logical Constraint Infeasibility Analysis
    _________________________________________

          1. Infeasible loser: FPGA                        FPGA01

    Filter pass #1
        Constraints Violated:

        Mandated: Must fund FPEL                        FPEL05

        SUB2    , Fund both or neitherFPEA                          FPEA01
                                   FPEL                           FPEL05

        SUB3    , Fund either but not bothFPEA                          FPEA01
                                       FPGA                           FPGA01


        Irreducible inconsistent set (IIS):

        Mandated: Must fund FPEL                        FPEL05

        Fund either but not both: FPEA                      FPEA01
                                  FPGA                      FPGA01

        Fund both or neither: FPEA                        FPEA01
```

```
                          FPEL                          FPEL05

 2. Infeasible loser: FPGA                         FPGA02

Filter pass #1
    Constraints Violated:

    Mandated: Must fund FPEL                          FPEL05

    SUB2   , Fund both or neitherFPEA                           FPEA01
                                 FPEL                           FPEL05

    Must fund FPGA01 before FPGA                          FPGA02

    SUB3   , Fund either but not bothFPEA                           FPEA01
                                     FPGA                           FPGA01


    Irreducible inconsistent set (IIS):

    Must fund FPGA01 before FPGA                          FPGA02

    Mandated: Must fund FPEL                          FPEL05

    Fund either but not both: FPEA                          FPEA01
                              FPGA                          FPGA01


    Fund both or neither: FPEA                          FPEA01
                          FPEL                          FPEL05
 3. Infeasible loser: FPSE                         FPSE01

Filter pass #1
    Constraints Violated:

    SUB5   , Fund either but not bothFPSA                           FPSA01
                                     FPSE                           FPSE01

    Mandated: Must fund FPSA                          FPSA01
    Mandated: Must fund FPSA                          FPSA06


    Irreducible inconsistent set (IIS):

    Mandated: Must fund FPSA                          FPSA01

    Fund either but not both: FPSA                          FPSA01
                              FPSE                          FPSE01


 4. Infeasible loser: FPSE                         FPSE02

Filter pass #1
    Constraints Violated:

    Must fund FPSE01 before FPSE                          FPSE02

    SUB5   , Fund either but not bothFPSA                           FPSA01
                                     FPSE                           FPSE01
```

```
  Mandated: Must fund FPSA                   FPSA01
  Mandated: Must fund FPSA                   FPSA06


  Irreducible inconsistent set (IIS):

  Must fund FPSE01 before FPSE                 FPSE02

  Mandated: Must fund FPSA                   FPSA01

  Fund either but not both: FPSA                FPSA01
                            FPSE                FPSE01


 5. Infeasible loser: FPSJ                  FPSJ01

Filter pass #1
  Constraints Violated:

  Mandated: Must fund FPSB                   FPSB01

  EXC3   , Fund either but not bothFPSB                     FPSB01
                                  FPSJ                     FPSJ01
                                  RA09                     RA0901


  Irreducible inconsistent set (IIS):

  Mandated: Must fund FPSB                   FPSB01

  Fund either but not both: FPSB                FPSB01
                            FPSJ                FPSJ01
                            RA09                RA0901


 6. Infeasible loser: RA08                  RA0801

Filter pass #1
  Constraints Violated:

  COMP3  , Fund both or neitherFPSE                  FPSE01
                              RA08                  RA0801

  SUB5   , Fund either but not bothFPSA                     FPSA01
                                  FPSE                     FPSE01

  Mandated: Must fund FPSA                   FPSA01
  Mandated: Must fund FPSA                   FPSA06


  Irreducible inconsistent set (IIS):

  Mandated: Must fund FPSA                   FPSA01

  Fund either but not both: FPSA                FPSA01
                            FPSE                FPSE01


  Fund both or neither: FPSE                  FPSE01
                        RA08                  RA0801
```

```
 7. Infeasible loser: RA08                       RA0806

Filter pass #1
    Constraints Violated:

    Must fund RA0801 before RA08                       RA0806

    COMP3   , Fund both or neitherFPSE                      FPSE01
                                 RA08                       RA0801

    SUB5    , Fund either but not bothFPSA                      FPSA01
                                     FPSE                       FPSE01

    Mandated: Must fund FPSA                       FPSA01
    Mandated: Must fund FPSA                       FPSA06


    Irreducible inconsistent set (IIS):


    Must fund RA0801 before RA08                       RA0806

    Mandated: Must fund FPSA                       FPSA01

    Fund either but not both: FPSA                       FPSA01
                              FPSE                       FPSE01


    Fund both or neither: FPSE                       FPSE01
                          RA08                       RA0801


 8. Infeasible loser: RA09                       RA0901

Filter pass #1
    Constraints Violated:

    Mandated: Must fund FPSB                       FPSB01

    EXC3    , Fund either but not bothFPSB                      FPSB01
                                     FPSJ                       FPSJ01
                                     RA09                       RA0901


    Irreducible inconsistent set (IIS):

    Mandated: Must fund FPSB                       FPSB01

    Fund either but not both: FPSB                       FPSB01
                              FPSJ                       FPSJ01
                              RA09                       RA0901


 9. Infeasible loser: RA09                       RA0902

Filter pass #1
```

```
    Constraints Violated:

    Mandated: Must fund FPSB                       FPSB01

    Must fund RA0901 before RA09                       RA0902


    EXC3    , Fund either but not bothFPSB                  FPSB01
                                      FPSJ                  FPSJ01
                                      RA09                  RA0901


    Irreducible inconsistent set (IIS):

    Must fund RA0901 before RA09                       RA0902

    Mandated: Must fund FPSB                       FPSB01

    Fund either but not both: FPSB                        FPSB01
                              FPSJ                        FPSJ01
                              RA09                        RA0901


10. Infeasible loser: RF01                       RF0101

Filter pass #1
    Constraints Violated:

    COMP4   , Fund both or neitherRA08                 RA0801
                                  RF01                 RF0101

    COMP3   , Fund both or neitherFPSE                 FPSE01
                                  RA08                 RA0801

    SUB5    , Fund either but not bothFPSA                 FPSA01
                                      FPSE                 FPSE01

    Mandated: Must fund FPSA                       FPSA01
    Mandated: Must fund FPSA                       FPSA06


    Irreducible inconsistent set (IIS):

    Mandated: Must fund FPSA                       FPSA01

    Fund either but not both: FPSA                        FPSA01
                              FPSE                        FPSE01


    Fund both or neither: FPSE                       FPSE01
                          RA08                       RA0801


    Fund both or neither: RA08                       RA0801
                          RF01                       RF0101


11. Infeasible loser: RF08                       RF0801
```

```
Filter pass #1
    Constraints Violated:

    COMP5    , Fund both or neitherRA08                    RA0801
                                   RF08                    RF0801

    COMP3    , Fund both or neitherFPSE                    FPSE01
                                   RA08                    RA0801

    SUB5     , Fund either but not bothFPSA                    FPSA01
                                       FPSE                    FPSE01

    Mandated: Must fund FPSA                       FPSA01
    Mandated: Must fund FPSA                       FPSA06


    Irreducible inconsistent set (IIS):

    Mandated: Must fund FPSA                       FPSA01

    Fund either but not both: FPSA                       FPSA01
                              FPSE                       FPSE01

    Fund both or neither: FPSE                       FPSE01
                          RA08                       RA0801

    Fund both or neither: RA08                       RA0801
                          RF08                       RF0801
```

D. MANDATED PROJECT ANALYSIS

1. Conflicting Mandates

Mandated Projects	**# Projects Forced-out**	**# Projects Enter**	**% Funding Before**	**% Funding After**	**Objective Function**
FPEL,05	16	5	100	0	889.88
FPSA,01	0	0	100	100	919.63
FPSA,06	0	0	100	80	916.65
FPSB,01	0	0	100	100	919.63

Table 1. Summary of Conflicts Analysis

```
#3  Analysis of Mandated MDEPs that Conflict with Losers
    ____________________________________________________


                                NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                _______ _____ _____ _____ _____ _____ _________
RDA3   RESULTS                  1377.14 2.27  0.26  1.88  0.09  11.65 919.63


 1.Un-mandate:             MDEP NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
```

```
                              ------- -------- ------ ------ ------ ------ ------ ---------
FPEL                          FPEL05 1327.13 2.20   0.43   2.09   0.52   15.02  889.88

                                                         War-value
                                                         ---------
    Forced out:  FPDB                        FPDB 06     0.09
                 FPDQ                        FPDQ 02     0.21
                 FPEA                        FPEA 01     3.03
                 FPEA                        FPEA 02     0.45
                 FPED                        FPED 01     3.80
                 FPED                        FPED 04     0.30
                 FPEE                        FPEE 01     5.16
                 FPEE                        FPEE 02     0.45
                 FPEL                        FPEL 02     1.83
                 FPEL                        FPEL 05     0.45
                 FPJC                        FPJC 06     0.13
                 FPLE                        FPLE 01     19.74
                 FPMK                        FPMK 06     0.20
                 FPSB                        FPSB 04     0.20
                 FPSG                        FPSG 01     11.01
                 FPSH                        FPSH 01     11.01

                                                         War-value
                                                         ---------
         Enter:  FL6X                        FL6X 01     3.52
                 FL6X                        FL6X 02     0.44
                 FPGA                        FPGA 01     48.50
                 FPGA                        FPGA 02     45.45
                 FPHB                        FPHB 01     3.52

 2.Un-mandate:                MDEP   NWARVAL NBAL1  NBAL2  PBAL1  PBAL2  NTURB  DEVIATION
                              ------- -------- ------ ------ ------ ------ ------ ---------
FPSA                          FPSA01 1377.14 2.27   0.26   1.88   0.09   11.65  919.63

    Funding change for mandate:  FPSA                        FPSA01
                                 Before: 746814     100.00%
                                  After: 746814     100.00%

 3.Un-mandate:                MDEP   NWARVAL NBAL1  NBAL2  PBAL1  PBAL2  NTURB  DEVIATION
                              ------- -------- ------ ------ ------ ------ ------ ---------
FPSA                          FPSA06 1372.71 2.30   0.27   1.91   0.09   3.73   916.65

    Funding change for mandate:  FPSA                        FPSA06
                                 Before: 6052849    100.00%
                                  After: 4842279     80.00%

 4.Un-mandate:                MDEP   NWARVAL NBAL1  NBAL2  PBAL1  PBAL2  NTURB  DEVIATION
                              ------- -------- ------ ------ ------ ------ ------ ---------
FPSB                          FPSB01 1377.14 2.27   0.26   1.88   0.09   11.65  919.63

    Funding change for mandate:  FPSB                        FPSB01
                                 Before: 365506     100.00%
                                  After: 365506     100.00%
```

2. All Mandates

#4 Analysis of All Mandated MDEPs

```
                                        NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                        _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                           1377.14 2.27  0.26  1.88  0.09  11.65 919.63

 1.Un-mandate:                   MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 ______ _______ _____ _____ _____ _____ _____ _________
FPEG                             FPEG01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63


    Funding change for mandate:  FPEG                              FPEG01
                                 Before: 1458705    100.00%
                                  After: 1458705    100.00%

 2.Un-mandate:                   MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 ______ _______ _____ _____ _____ _____ _____ _________
FPEL                             FPEL05 1327.09 2.14  0.49  2.13  0.49  14.60 889.85

                                                          War-value
                                                          _________
    Forced out:  FPDQ                  FPDQ 02            0.21
                 FPEA                  FPEA 01            3.03
                 FPEA                  FPEA 02            0.45
                 FPED                  FPED 01            3.80
                 FPED                  FPED 04            0.30
                 FPEE                  FPEE 01            5.16
                 FPEE                  FPEE 02            0.45
                 FPEL                  FPEL 02            1.83
                 FPEL                  FPEL 05            0.45
                 FPJC                  FPJC 06            0.13
                 FPLE                  FPLE 01            19.74
                 FPMK                  FPMK 06            0.20
                 FPSB                  FPSB 04            0.20
                 FPSG                  FPSG 01            11.01
                 FPSH                  FPSH 01            11.01

                                                          War-value
                                                          _________
         Enter:  FL6X                  FL6X 01            3.52
                 FL6X                  FL6X 02            0.44
                 FPGA                  FPGA 01            48.50
                 FPGA                  FPGA 02            45.45
                 FPHB                  FPHB 01            3.52

 3.Un-mandate:                   MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 ______ _______ _____ _____ _____ _____ _____ _________
FPFL                             FPFL01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:  FPFL                              FPFL01
                                 Before: 705731     100.00%
                                  After: 705731     100.00%

 4.Un-mandate:                   MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 ______ _______ _____ _____ _____ _____ _____ _________
FPJC                             FPJC01 1372.57 2.27  0.24  1.80  0.15  5.37  916.56
```

```
    Funding change for mandate:  FPJC                       FPJC01
                                 Before: 8278850   100.00%
                                  After: 5737874    69.31%

 5.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPMK                       FPMK01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:  FPMK                       FPMK01
                                 Before: 666772    100.00%
                                  After: 666772    100.00%

 6.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPMM                       FPMM01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:  FPMM                       FPMM01
                                 Before: 2048522   100.00%
                                  After: 2048522   100.00%

 7.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPNC                       FPNC01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:  FPNC                       FPNC01
                                 Before: 527576    100.00%
                                  After: 527576    100.00%

 8.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPSA                       FPSA01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63


                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                     1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:  FPSA                       FPSA01
                                 Before: 746814    100.00%
                                  After: 746814    100.00%

 9.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPSA                       FPSA06 1372.71 2.30  0.27  1.91  0.09  3.73  916.65

    Funding change for mandate:  FPSA                       FPSA06
                                 Before: 6052849   100.00%
                                  After: 4842279    80.00%

10.Un-mandate:             MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPSB                       FPSB01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63
```

```
    Funding change for mandate:   FPSB                          FPSB01
                                  Before: 365506     100.00%
                                   After: 365506     100.00%

11.Un-mandate:              MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                           ______ _______ _____ _____ _____ _____ _____ _________
FPWB                       FPWB01 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

    Funding change for mandate:   FPWB                          FPWB01
                                  Before: 1929687    100.00%
                                   After: 1929687    100.00%
```

E. FEASIBLE PROJECT ANALYSIS

Forced in Projects	# Projects Forced-out	# Projects Followed in	Objective Function
FL6X,01	2	3	921.67
FL6X,02	2	3	921.67
FPHB,01	2	3	921.67
FPJB,06	0	0	920.50
FPLF,06	0	0	920.88
FPLG,02	0	0	919.74
FPLK,02	2	0	919.96
FPLK,04	0	0	921.06
FPMM,04	0	0	921.38
FPNB,01	2	0	960.72
FPNE,05	0	0	920.30
FPSD,01	5	1	1110.85
FPSD,04	5	2	1111.27
FPSD,06	5	1	1110.85

Table 2. Summary of Feasible Project Analysis

#5 Analysis of Feasible Losers

```
                              NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                              _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                 1377.14 2.27  0.26  1.88  0.09  11.65 919.63


 1.Force-in:             MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                         _____ _______ _____ _____ _____ _____ _____ _________
FL6X                      FL6X011382.17 2.46  0.34  1.74  0.08  10.11 921.67

                                                    War-value
                                                    _________
   Forced out: FPSG                     FPSG 01     11.01
               FPSH                     FPSH 01     11.01

                                                    War-value
                                                    _________
  Followed-in: FL6X                    FL6X 02      0.44
               FPHB                    FPHB 01      3.52
               FPLG                    FPLG 02      0.15


 2.Force-in:             MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                         _____ _______ _____ _____ _____ _____ _____ _________
FL6X                      FL6X021382.17 2.46  0.34  1.74  0.08  10.11 921.67

                                                    War-value
                                                    _________
   Forced out: FPSG                     FPSG 01     11.01
               FPSH                     FPSH 01     11.01

                                                    War-value
                                                    _________
  Followed-in: FL6X                    FL6X 01      3.52
               FPHB                    FPHB 01      3.52
               FPLG                    FPLG 02      0.15


 3.Force-in:             MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                         _____ _______ _____ _____ _____ _____ _____ _________
FPHB                      FPHB011382.17 2.46  0.34  1.74  0.08  10.11 921.67

                                                    War-value
                                                    _________
   Forced out: FPSG                     FPSG 01     11.01
               FPSH                     FPSH 01     11.01

                                                    War-value
                                                    _________
  Followed-in: FL6X                    FL6X 01      3.52
               FL6X                    FL6X 02      0.44
               FPLG                    FPLG 02      0.15


 4.Force-in:             MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                         _____ _______ _____ _____ _____ _____ _____ _________
```

```
FPJB                 FPJB061378.44 2.28  0.26  1.87  0.11  12.89 920.50


 5.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPLF                 FPLF061379.00 2.30  0.27  1.85  0.16  11.84 920.88


 6.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPLG                 FPLG021377.29 2.31  0.26  1.83  0.18  11.65 919.74


 7.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPLK                 FPLK021377.61 2.30  0.29  1.85  0.09  11.54 919.96

                                                 War-value
                                                 _________
     Forced out:  FPXX                FPXX 01    0.80
                  FPXX                FPXX 06    0.20


 8.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPLK                 FPLK041379.27 2.28  0.25  1.89  0.09  11.04 921.06


 9.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPMM                 FPMM041379.75 2.27  0.27  1.89  0.09  12.90 921.38


10.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPNB                 FPNB011436.45 2.22  0.26  1.83  0.08  12.72 960.72

                                                 War-value
                                                 _________
     Forced out:  FPDC                FPDC 01    23.83
                  FPDC                FPDC 06    0.52


11.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPNE                 FPNE051378.14 2.27  0.26  1.87  0.10  11.97 920.30


12.Force-in:         MDEP   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                    ______ _______ _____ _____ _____ _____ _____ _________
FPSD                 FPSD011660.63 2.22  0.16  1.81  0.16  8.45  1110.85

                                                 War-value
```

```
                                                           _________
     Forced out:  FPDC                        FPDC 01      23.83
                  FPDC                        FPDC 06      0.52
                  FPDQ                        FPDQ 02      0.21
                  FPXX                        FPXX 01      0.80
                  FPXX                        FPXX 06      0.20

                                                           War-value
                                                           _________
   Followed-in:   FPSD                       FPSD 06       0.29


13.Force-in:                 MDEP  NWARVAL  NBAL1  NBAL2  PBAL1  PBAL2  NTURB  DEVIATION
                            _____  _______  _____  _____  _____  _____  _____  _________
FPSD                         FPSD041661.25  2.21   0.18   1.78   0.21   7.91   1111.27


                                                           War-value
                                                           _________
     Forced out:  FPDC                        FPDC 01      23.83
                  FPDC                        FPDC 06      0.52
                  FPDQ                        FPDQ 02      0.21
                  FPXX                        FPXX 01      0.80
                  FPXX                        FPXX 06      0.20

                                                           War-value
                                                           _________
   Followed-in:   FPSD                       FPSD 01       6.86
                  FPSD                       FPSD 06       0.29


14.Force-in:                 MDEP  NWARVAL  NBAL1  NBAL2  PBAL1  PBAL2  NTURB  DEVIATION
                            _____  _______  _____  _____  _____  _____  _____  _________
FPSD                         FPSD061660.63  2.22   0.16   1.81   0.16   8.45   1110.85

                                                           War-value
                                                           _________
     Forced out:  FPDC                        FPDC 01      23.83
                  FPDC                        FPDC 06      0.52
                  FPDQ                        FPDQ 02      0.21
                  FPXX                        FPXX 01      0.80
                  FPXX                        FPXX 06      0.20

                                                           War-value
                                                           _________
   Followed-in:   FPSD                       FPSD 01       6.86
```

APPENDIX E. BUDGET AND OSCOST INFEASIBILITY

This appendix contains the complete results from the budget and operating and support cost tests.

A. BUDGET INFEASIBILITY

Case	Minimum Fraction of Total Aspired to be Funded	Minimum Annual Funding Level	Funding Policy for Mandates	# Projects Not Funded Because They Violate the Budget Constraint
1	.6 for "01" increments .8 for all others	0	Full	15
2	.6 for "01" increments .8 for all others	0	Partial	2
3	0	.75	Full	25
4	0	.75	Partial	3

Table 1. Budget Infeasibility Results

1. Case 1

```
#1  Budget and OSCOST Feasibility Analysis


    Budget profile:     FY94 4000000
                        FY95 4000000
                        FY96 4000000
                        FY97 4000000
                        FY98 4000000
                        FY99 3000000
                        FY00 3000000
                        FY01 3000000
                        FY02 3000000
                        FY03 3000000
                        FY04 5000000
                        FY05 5000000
                        FY06 5000000
                        FY07 5000000
                        FY08 5000000

    Maximum total OSCOST:   999999999

    Result:   1. FPGA                       FPGA01
                 Violates the total budget constraint
```

```
 2. FPGA                        FPGA02
    Violates the total budget constraint

 3. FPLF                        FPLF06
    Violates the total budget constraint

 4. FPLG                        FPLG02
    Violates the total budget constraint

 5. FPLK                        FPLK02
    Violates the total budget constraint

 6. FPLK                        FPLK04
    Violates the total budget constraint

 7. FPMM                        FPMM04
    Violates the total budget constraint

 8. FPNB                        FPNB01
    Violates the total budget constraint

 9. FPNE                        FPNE05
    Violates the total budget constraint

10. FPSD                        FPSD01
    Violates the total budget constraint

11. FPSD                        FPSD04
     Violates the total budget constraint

12. FPSD                        FPSD06
    Violates the total budget constraint

13. FPSE                        FPSE02
    Violates the total budget constraint

14. FPSJ                        FPSJ01
    Violates the total budget constraint

15. RA08                        RA0806
    Violates the total budget constraint
```

2. Case 2

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:    FY94 4000000
                       FY95 4000000
                       FY96 4000000
                       FY97 4000000
                       FY98 4000000
                       FY99 3000000
                       FY00 3000000
                       FY01 3000000
                       FY02 3000000
                       FY03 3000000
                       FY04 5000000
```

```
                  FY05 5000000
                  FY06 5000000
                  FY07 5000000
                  FY08 5000000

Maximum total OSCOST:   999999999

Result:   1. FPGA                          FPGA01
             Violates the total budget constraint

          2. FPSE                          FPSE02
             Violates the total budget constraint
```

3. Case 3

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:     FY94 2000000
                        FY95 10000000
                        FY96 10000000
                        FY97 10000000
                        FY98 2000000
                        FY99 11000000
                        FY00 11000000
                        FY01 11000000
                        FY02 2000000
                        FY03 11000000
                        FY04 12000000
                        FY05 12000000
                        FY06 2000000
                        FY07 12000000
                        FY08 12000000

    Maximum total OSCOST:   999999999

    Result:   1. FL6X                          FL6X01
                 Violates the budget constraint in year:   FY94
                                                           FY98


              2. FL6X                          FL6X02
                 Violates the budget constraint in year:   FY94
                                                           FY98


              3. FPGA                          FPGA01
                 Violates the budget constraint in year:   FY94
                                                           FY98
                                                           FY02
                                                           FY06


              4. FPGA                          FPGA02
                 Violates the budget constraint in year:   FY94
                                                           FY98


              5. FPHB                          FPHB01
                 Violates the budget constraint in year:   FY94
```

```
                                                         FY98


  6. FPJB                          FPJB06
     Violates the budget constraint in year:             FY94
                                                         FY98


  7. FPLF                          FPLF06
     Violates the budget constraint in year:             FY94
                                                         FY98


  8. FPLG                          FPLG02
     Violates the budget constraint in year:             FY94
                                                         FY98


  9. FPLK                          FPLK02
     Violates the budget constraint in year:             FY94
                                                         FY98


 10. FPLK                          FPLK04
     Violates the budget constraint in year:             FY94
                                                         FY98


 11. FPMM                          FPMM04
     Violates the budget constraint in year:             FY94
                                                         FY98


 12. FPNB                          FPNB01
     Violates the budget constraint in year:             FY94
                                                         FY98


 13. FPNE                          FPNE05
     Violates the budget constraint in year:             FY94
                                                         FY98


 14. FPSD                          FPSD01
     Violates the budget constraint in year:             FY94
                                                         FY98


 15. FPSD                          FPSD04
     Violates the budget constraint in year:             FY94
                                                         FY98


 16. FPSD                          FPSD06
     Violates the budget constraint in year:             FY94
                                                         FY98


 17. FPSE                          FPSE01
     Violates the budget constraint in year:             FY94
                                                         FY98
```

```
18. FPSE                                 FPSE02
    Violates the budget constraint in year:    FY94
                                               FY98
                                               FY02
                                               FY06


19. FPSJ                                 FPSJ01
    Violates the budget constraint in year:    FY94
                                               FY98
                                               FY06


20. RA08                                 RA0801
    Violates the budget constraint in year:    FY94
                                               FY98


21. RA08                                 RA0806
    Violates the budget constraint in year:    FY94
                                               FY98


22. RA09                                 RA0901
    Violates the budget constraint in year:    FY94
                                               FY98


23. RA09                                 RA0902
    Violates the budget constraint in year:    FY94
                                               FY98


24. RF01                                 RF0101
    Violates the budget constraint in year:    FY94
                                               FY98


25. RF08                                 RF0801
    Violates the budget constraint in year:    FY94
                                               FY98
```

4. Case 4

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:    FY94 2000000
                       FY95 10000000
                       FY96 10000000
                       FY97 10000000
                       FY98 2000000
                       FY99 11000000
                       FY00 11000000
                       FY01 11000000
                       FY02 2000000
                       FY03 11000000
```

```
                    FY04 12000000
                    FY05 12000000
                    FY06 2000000
                    FY07 12000000
                    FY08 12000000

Maximum total OSCOST:   999999999

Result:   1. FPGA                        FPGA01
             Violates the budget constraint in year:   FY94
                                                       FY98
                                                       FY02
                                                       FY06


          2. FPSE                        FPSE02
             Violates the budget constraint in year:   FY98
                                                       FY06


          3. FPSJ                        FPSJ01
             Violates the budget constraint in year:   FY06
```

B. OSCOST INFEASIBILITY

Case	Maximum Allowable Operating and Support Cost	Funding Policy for Mandates	# Projects Not Funded Because They Violate the Maximum Operating and Support Costs
1	$50 Billion	Full	13
2	$50 Billion	Partial	1

Table 2. OSCOST infeasibility results for the baseline data with the maximum allowable operating and support cost reduced to cause infeasibility. The effect of the funding policy for mandated projects is evident. There is a substantial reduction in the number of projects that are not funded because they violate the maximum allowable operating and support costs.

1. Case 1

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:    FY94 10000000
                       FY95 10000000
                       FY96 10000000
                       FY97 10000000
                       FY98 10000000
                       FY99 11000000
```

```
                   FY00 11000000
                   FY01 11000000
                   FY02 11000000
                   FY03 11000000
                   FY04 12000000
                   FY05 12000000
                   FY06 12000000
                   FY07 12000000
                   FY08 12000000

Maximum total OSCOST:   50000000

Result:    1. FPGA                       FPGA01
              Does not adhere to the maximum operation and support costs.

           2. FPGA                       FPGA02
              Does not adhere to the maximum operation and support costs.

           3. FPLF                       FPLF06
              Does not adhere to the maximum operation and support costs.

           4. FPLG                       FPLG02
              Does not adhere to the maximum operation and support costs.

           5. FPLK                       FPLK02
              Does not adhere to the maximum operation and support costs.

           6. FPLK                       FPLK04
              Does not adhere to the maximum operation and support costs.

           7. FPMM                       FPMM04
              Does not adhere to the maximum operation and support costs.

           8. FPSD                       FPSD01
              Does not adhere to the maximum operation and support costs.

           9. FPSD                       FPSD06
              Does not adhere to the maximum operation and support costs.

          10. FPSE                       FPSE01
              Does not adhere to the maximum operation and support costs.

          11. FPSE                       FPSE02

              Does not adhere to the maximum operation and support costs.

          12. FPSJ                       FPSJ01
              Does not adhere to the maximum operation and support costs.

          13. RA08                       RA0801
              Does not adhere to the maximum operation and support costs.
```

2. Case 2

```
#1  Budget and OSCOST Feasibility Analysis
    --------------------------------------


    Budget profile:    FY94 10000000
                       FY95 10000000
```

```
                   FY96 10000000
                   FY97 10000000
                   FY98 10000000
                   FY99 11000000
                   FY00 11000000
                   FY01 11000000
                   FY02 11000000
                   FY03 11000000
                   FY04 12000000
                   FY05 12000000
                   FY06 12000000
                   FY07 12000000
                   FY08 12000000

Maximum total OSCOST:   50000000

Result:   1. RA08                          RA0801
             Does not adhere to the maximum operation and support costs.
```

APPENDIX F. ANALYSIS OF MULTIPLE LOSERS AND MANDATES

This appendix shows the results obtained after un-mandating a group of mandated projects, as well as the results from forcing in a group of feasible losers.

A. BUDGET PROFILE

```
#1  Budget and OSCOST Feasibility Analysis
    ______________________________________


    Budget profile:    FY94 10000000
                       FY95 10000000
                       FY96 10000000
                       FY97 10000000
                       FY98 10000000
                       FY99 11000000
                       FY00 11000000
                       FY01 11000000
                       FY02 11000000
                       FY03 11000000
                       FY04 12000000
                       FY05 12000000
                       FY06 12000000
                       FY07 12000000
                       FY08 12000000

    Maximum total OSCOST:   999999999

    Result:  All losers are budget and OSCOST feasible
```

B. UN-MANDATING A GROUP OF MANDATED PROJECTS

```
#2  Analysis of a Specified Group of Mandated MDEPs
    _______________________________________________


                                   NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                   _______ _____ _____ _____ _____ _____ _________
RDA3   RESULTS                     1377.14 2.27  0.26  1.88  0.09  11.65 919.63

Group Un-Mandated Result:    MDEP  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                             _____ _______ _____ _____ _____ _____ _____ _________
                                   1192.24 2.43  0.35  2.22  0.56  13.77 799.03

                                                     War-value
                                                     _________
 1. FPEL                        FPEL05               0.45
 2. FPSA                        FPSA01               9.69
```

```
  3. FPSA                    FPSA06                  0.80
  4. FPSB                    FPSB01                  9.69

                                                     War-value
                                                     _________
     Forced out:  FPDB                 FPDB 06       0.09
                  FPDQ                 FPDQ 02       0.21
                  FPEA                 FPEA 01       3.03
                  FPEA                 FPEA 02       0.45
                  FPED                 FPED 01       3.80
                  FPED                 FPED 04       0.30
                  FPEE                 FPEE 01       5.16
                  FPEE                 FPEE 02       0.45
                  FPEL                 FPEL 02       1.83
                  FPEL                 FPEL 05       0.45
                  FPJC                 FPJC 02       0.32
                  FPJC                 FPJC 06       0.13
                  FPLE                 FPLE 01       19.74
                  FPSA                 FPSA 01       9.69
                  FPSA                 FPSA 06       0.80
                  FPSB                 FPSB 04       0.20
                  FPSF                 FPSF 01       8.06
                  FPSG                 FPSG 01       11.01
                  FPSH                 FPSH 01       11.01

                                                     War-value
                                                     _________
           Enter: FL6X                 FL6X 01       3.52
                  FL6X                 FL6X 02       0.44
                  FPGA                 FPGA 01       48.50
                  FPGA                 FPGA 02       45.45
                  FPHB                 FPHB 01       3.52
                  FPSE                 FPSE 01       15.64
                  FPSE                 FPSE 02       4.44
                  RA08                 RA08 01       3.23
                  RF01                 RF01 01       1.61
                  RF08                 RF08 01       1.67


    Funding change for mandate:  FPSB                     FPSB01
                                 Before: 365506    100.00%
                                  After: 365506    100.00%

  #2  Summary of Losers
      _________________

  MDEP TITLE              MDEP/INC   TOT-ASPIRED   WAR-VALUE
  __________              ________   ___________   _________
  FPDB                    FPDB06     1836800       0.09
  FPDQ                    FPDQ02     650800        0.21
  FPEA                    FPEA01     609387        3.03
  FPEA                    FPEA02     129000        0.45
  FPED                    FPED01     375000        3.80
  FPED                    FPED04     487089        0.30
  FPEE                    FPEE01     194949        5.16
  FPEE                    FPEE02     299435        0.45
  FPEL                    FPEL02     5313792       1.83
  FPEL                    FPEL05     1728400       0.45
  FPJB                    FPJB06     582917        0.13
  FPJC                    FPJC02     3232000       0.32
```

FPJC	FPJC06	548523	0.13
FPLE	FPLE01	179761	19.74
FPLF	FPLF06	1778500	0.15
FPLG	FPLG02	1896100	0.15
FPLK	FPLK02	1253500	0.80
FPLK	FPLK04	1341264	0.20
FPMM	FPMM04	1332600	0.20
FPNB	FPNB01	1300461	25.80
FPNE	FPNE05	692100	0.12
FPSA	FPSA01	746814	9.69
FPSA	FPSA06	6052849	0.80
FPSB	FPSB04	1052000	0.20
FPSD	FPSD01	4385149	6.86
FPSD	FPSD04	1381651	0.29
FPSD	FPSD06	3496890	0.29
FPSF	FPSF01	2923196	8.06
FPSG	FPSG01	6015816	11.01
FPSH	FPSH01	2642575	11.01
FPSJ	FPSJ01	12909581	1.62
RA08	RA0806	1086904	0.16
RA09	RA0901	127800	3.23
RA09	RA0902	11347	0.20

C. FORCING IN A GROUP OF FEASIBLE LOSERS

#3 Analysis of a Specified Group of Feasible Losers

	NWARVAL	NBAL1	NBAL2	PBAL1	PBAL2	NTURB	DEVIATION
RDA3 RESULTS	1377.14	2.27	0.26	1.88	0.09	11.65	919.63

Group Force-in Result:	MDEP	NWARVAL	NBAL1	NBAL2	PBAL1	PBAL2	NTURB	DEVIATION
		1384.08	2.29	0.29	1.85	0.17	14.36	924.28

		War-value
1. FPJB	FPJB06	0.13
2. FPLF	FPLF06	0.15
3. FPMM	FPMM04	0.20

		War-value
Forced out: FPDQ	FPDQ 02	0.21

#3 Summary of Losers

MDEP TITLE	MDEP/INC	TOT-ASPIRED	WAR-VALUE
FL6X	FL6X01	98700	3.52
FL6X	FL6X02	111500	0.44
FPDQ	FPDQ02	650800	0.21
FPGA	FPGA01	35381174	48.50
FPGA	FPGA02	1905700	45.45
FPHB	FPHB01	620551	3.52
FPLG	FPLG02	1896100	0.15

FPLK	FPLK02	1253500	0.80
FPLK	FPLK04	1341264	0.20
FPNB	FPNB01	1300461	25.80
FPNE	FPNE05	692100	0.12
FPSD	FPSD01	4385149	6.86
FPSD	FPSD04	1381651	0.29
FPSD	FPSD06	3496890	0.29
FPSE	FPSE01	717622	15.64
FPSE	FPSE02	17100303	4.44
FPSJ	FPSJ01	12909581	1.62
RA08	RA0801	256148	3.23
RA08	RA0806	1086904	0.16
RA09	RA0901	127800	3.23
RA09	RA0902	11347	0.20
RF01	RF0101	240053	1.61
RF08	RF0801	608248	1.67

APPENDIX G. SENSITIVITY ANALYSIS ON THE BUDGET

The results for the three models investigated to conduct sensitivity analysis on the budget allocation are shown here. They are: Model 1- RDA^3 unchanged, Model 2- RDA^3 with the originally funded projects fixed into the solution, Model 3- RDA^3 with variable persistence applied.

A. FEASIBLE BUDGET PROFILE

```
    Budget profile:    FY94 8000000
                       FY95 8000000
                       FY96 8000000
                       FY97 8000000
                       FY98 8000000
                       FY99 9000000
                       FY00 9000000
                       FY01 9000000
                       FY02 9000000
                       FY03 9000000
                       FY04 10000000
                       FY05 10000000
                       FY06 10000000
                       FY07 10000000
                       FY08 10000000
```

1. Using the original RDA^3 model

```
#1  Budget Analysis Before Decision
    ________________________________


                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                     1377.14 2.27  0.26  1.88  0.09  11.65 919.63


                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  _______ _____ _____ _____ _____ _____ _________
New results:                      1563.23 2.14  0.25  1.94  0.44  6.94  1044.55


    Budget profile:    FY94 8000000
                       FY95 8000000
                       FY96 8000000
                       FY97 8000000
                       FY98 8000000
                       FY99 9000000
                       FY00 9000000
```

```
                       FY01 9000000
                       FY02 9000000
                       FY03 9000000
                       FY04 10000000
                       FY05 10000000
                       FY06 10000000
                       FY07 10000000
                       FY08 10000000


                                                           War-value
                                                           ---------
    Forced out: FPDM                        FPDM 01        0.13
                FPDQ                        FPDQ 02        0.21
                FPEQ                        FPEQ 01        0.30
                FPJB                        FPJB 02        0.37
                FPJC                        FPJC 06        0.13
                FPMC                        FPMC 05        0.28
                FPMH                        FPMH 02        0.58
                FPMH                        FPMH 03        0.20
                FPMK                        FPMK 04        0.28
                FPMK                        FPMK 06        0.20
                FPNA                        FPNA 01        1.36
                FPNE                        FPNE 02        0.49
                FPSB                        FPSB 04        0.20
                FPWC                        FPWC 05        0.11
                FPXK                        FPXK 02        0.68
                RA31                        RA31 01        0.29
                RA31                        RA31 06        0.20
                RE02                        RE02 01        0.37
                RF02                        RF02 02        0.11
                RF03                        RF03 06        0.11
                RF09                        RF09 06        0.16
-------------------------------------------------------------------------------
TOTALS: old-->  % of Budget: 95.89          2.6068E+8 1.5823E+8 60.70
        new-->  % of Budget: 99.88          2.6068E+8 1.3484E+8 51.73
```

2. Fixing the Previous Solution

```
#3  Budget Analysis After Decision (old solution fixed)
    ------------------------------


#4  Budget and OSCOST Feasibility Analysis (for budget analysis)
    --------------------------------------


    Budget profile:    FY94 8000000
                       FY95 8000000
                       FY96 8000000
                       FY97 8000000
                       FY98 8000000
                       FY99 9000000
                       FY00 9000000
                       FY01 9000000
                       FY02 9000000
                       FY03 9000000
```

```
                         FY04 10000000
                         FY05 10000000
                         FY06 10000000
                         FY07 10000000
                         FY08 10000000

    Maximum total OSCOST:    999999999

    Result:  The original solution is budget and OSCOST feasible

                                 NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                    1377.14 2.27  0.26  1.88  0.09  11.65 919.63

                                 NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 _______ _____ _____ _____ _____ _____ _________
New results:                     1673.16 2.34  0.36  2.25  0.45  19.92 1118.02

TOTALS: old-->   % of Budget: 95.89          2.6068E+8 1.5823E+8 60.70
        new-->   % of Budget: 100.00         2.6068E+8 1.3500E+8 51.79
```

3. Applying Variable Persistence

```
#2  Budget Analysis After Decision (with persistence)
    ______________________________


                                 NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                    1377.14 2.27  0.26  1.88  0.09  11.65 919.63

                                 NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                 _______ _____ _____ _____ _____ _____ _________
New results:                     1673.16 2.34  0.36  2.25  0.45  19.92 1118.02

    Budget profile:      FY94 8000000
                         FY95 8000000
                         FY96 8000000
                         FY97 8000000
                         FY98 8000000
                         FY99 9000000
                         FY00 9000000
                         FY01 9000000
                         FY02 9000000
                         FY03 9000000
                         FY04 10000000
                         FY05 10000000
                         FY06 10000000
                         FY07 10000000
                         FY08 10000000
```

```
TOTALS: old-->   % of Budget: 95.89        2.6068E+8 1.5823E+8 60.70
        new-->   % of Budget: 100.00       2.6068E+8 1.3500E+8 51.79
```

B. INFEASIBLE BUDGET PROFILE

```
    Budget profile:     FY94 8000000
                        FY95 8000000
                        FY96 8000000
                        FY97 8000000
                        FY98 8000000
                        FY99 8000000
                        FY00 8000000
                        FY01 8000000
                        FY02 8000000
                        FY03 8000000
                        FY04 8000000
                        FY05 8000000
                        FY06 8000000
                        FY07 8000000
                        FY08 8000000
```

1. Using the Original RDA^3 Model

```
#1  Budget Analysis Before Decision
    ______________________________

                              NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                              _______ _____ _____ _____ _____ _____ _________
RDA3  RESULTS                 1377.14 2.27  0.26  1.88  0.09  11.65 919.63

                              NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                              _______ _____ _____ _____ _____ _____ _________
New results:                  1588.86 2.15  0.70  2.03  0.50  3.93  1060.41

    Budget profile:     FY94 8000000
                        FY95 8000000
                        FY96 8000000
                        FY97 8000000
                        FY98 8000000
                        FY99 8000000
                        FY00 8000000
                        FY01 8000000
                        FY02 8000000
                        FY03 8000000
                        FY04 8000000
                        FY05 8000000
                        FY06 8000000
                        FY07 8000000
                        FY08 8000000

                                                      War-value
                                                      _________
    Forced out:  FPDE                  FPDE 02        0.48
                 FPDM                  FPDM 01        0.13
```

```
                 FPDQ                        FPDQ 02       0.21
                 FPEQ                        FPEQ 01       0.30
                 FPJB                        FPJB 02       0.37
                 FPJC                        FPJC 06       0.13
                 FPMC                        FPMC 05       0.28
                 FPMH                        FPMH 02       0.58
                 FPMH                        FPMH 03       0.20
                 FPMK                        FPMK 04       0.28
                 FPMK                        FPMK 06       0.20
                 FPNA                        FPNA 01       1.36
                 FPNE                        FPNE 02       0.49
                 FPNG                        FPNG 01       0.17
                 FPSB                        FPSB 04       0.20
                 FPSG                        FPSG 01       11.01
                 FPSH                        FPSH 01       11.01
                 FPSL                        FPSL 01       0.20
                 FPWC                        FPWC 05       0.11
                 FPXK                        FPXK 02       0.68
                 RA31                        RA31 01       0.29
                 RA31                        RA31 06       0.20
                 RE02                        RE02 01       0.37
                 RF02                        RF02 02       0.11
                 RF03                        RF03 06       0.11
                 RF09                        RF09 06       0.16
                 RJS2                        RJS2 05       0.41

                                                           War-value
                                                           _________
         Enter:  FL6X                        FL6X 01       3.52
                 FL6X                        FL6X 02       0.44
                 FPHB                        FPHB 01       3.52

_______________________________________________________________________________
TOTALS: old-->   % of Budget: 95.89          2.6068E+8 1.5823E+8 60.70
        new-->   % of Budget: 97.84          2.6068E+8 1.1740E+8 45.04
```

2. Fixing the Previous Solution

```
#3  Budget Analysis After Decision (old solution fixed)
    ______________________________


#4  Budget and OSCOST Feasibility Analysis (for budget analysis)
    ______________________________________


    Budget profile:    FY94 8000000
                       FY95 8000000
                       FY96 8000000
                       FY97 8000000
                       FY98 8000000
                       FY99 8000000
                       FY00 8000000
                       FY01 8000000
                       FY02 8000000
                       FY03 8000000
                       FY04 8000000
                       FY05 8000000
                       FY06 8000000
```

```
                       FY07 8000000
                       FY08 8000000

    Maximum total OSCOST:   999999999

                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  ------- ----- ----- ----- ----- ----- ---------
RDA3  RESULTS                     1377.14 2.27  0.26  1.88  0.09  11.65 919.63


    Infeasible budget level
```

3. Applying Variable Persistence

```
#2  Budget Analysis After Decision (with persistence)
    ------------------------------


                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  ------- ----- ----- ----- ----- ----- ---------
RDA3  RESULTS                     1377.14 2.27  0.26  1.88  0.09  11.65 919.63

                                  NWARVAL NBAL1 NBAL2 PBAL1 PBAL2 NTURB DEVIATION
                                  ------- ----- ----- ----- ----- ----- ---------
New results:                      2030.58 2.31  0.54  2.34  0.50  79.16 1354.31


    Budget profile:    FY94 8000000
                       FY95 8000000
                       FY96 8000000
                       FY97 8000000
                       FY98 8000000
                       FY99 8000000
                       FY00 8000000
                       FY01 8000000
                       FY02 8000000
                       FY03 8000000
                       FY04 8000000
                       FY05 8000000
                       FY06 8000000
                       FY07 8000000
                       FY08 8000000



                                                          War-value
                                                          ---------
    Forced out:  FPSL                        FPSL 01      0.20

------------------------------------------------------------------------------
TOTALS: old-->   % of Budget: 95.89          2.6068E+8 1.5823E+8 60.70
        new-->   % of Budget: 100.00         2.6068E+8 1.2000E+8 46.03
```

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